University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Theses and Dissertations in Animal Science

Animal Science Department

Summer 6-30-2011

Study of the Innovative Self-Powered Sensor Based Smart Wireless Identification and Tracking Tag for Production Agriculture Application

Kumud Dhakal
University of Nebraska at Lincoln, kumud.dhakal@huskers.unl.edu

STUDY OF THE INNOVATIVE SELF-POWERED SENSOR BASED SMART WIRELESS IDENTIFICATION AND TRACKING TAG FOR PRODUCTION AGRICULTURE APPLICATION

by

Kumud Dhakal

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professor Jeffrey F. Keown

Lincoln, Nebraska

August, 2011

STUDY OF THE INNOVATIVE SELF-POWERED SENSOR BASED SMART WIRELESS IDENTIFICATION AND TRACKING TAG FOR PRODUCTION AGRICULTURE APPLICATION

Kumud Dhakal, M. S.

University of Nebraska, 2011

Advisor: Jeffrey F. Keown

A prototype smart animal ear tag has been developed to meet the United States Department of Agriculture (USDA) animal disease traceability requirement. This novel ‘Smart Tag’ is a self–powered device capable of complete animal identification and tracking. Information on animal health, breeding and vaccination records can also be locally stored and retrieved from these small, economical and securely accessible wireless tags. These smart tags are capable of self-organizing into wireless ad-hoc networks for data reporting and retrieval. This work presents study of the distance coverage of a ‘Smart Tag’ and a cost-benefit analysis of ‘Smart Tag’ implementation. The mean distance range for a single hop (battery source of power) was 22.6 ± 1.38 m and for a single hop (solar source of power) was 29 m. The total distance coverage using six ‘Smart Tags’ (battery source of power) plus the central computer receiving station using multi–hop communication was 136 ± 1.58 m and for two ‘Smart Tags’ (solar source of power) distance coverage was 54 m. However, due to their ad-hoc wireless nature, the true size of the network is limited by the number of available ‘Smart Tags’. The more tags are connected, the larger the network will become and the larger the coverage area will be. Temperature, humidity and wind speed had no effect ($p > 0.05$) on packets received within the transmission range.

The economic analysis showed that initial cost of a ‘Smart Tag’ system is much greater than for current electronic RFID tags found in market due to its unique features such as being self-powered, wireless, reusable, having greater distance coverage, and having data privacy, however, the benefits may outweigh the investment cost compared to other animal identification technologies.

Key words: animal identification, self-powered, smart tag, tracking, wireless

Acknowledgements

I am immensely grateful to my advisor Dr. Jeffrey F. Keown for taking me as a graduate student in the masters program. He provided constant support, encouragement and guidance even in personal matters throughout my graduate program. It is an honor for me to have Dr. L Dale Van Vleck on my graduate committee. I have learnt much from him. His efforts in completion of my thesis are appreciated. I extend my gratitude to my committee members Dr. Hamid R. Sharif and Dr. Kathy Hanford for their assistance in the completion of my program. Without their valuable support and encouragement, I would not have been able to finish my thesis work.

I owe my deepest gratitude to my office mates Jose Alberto Barron Lopez and Sungwon Park. I always remember their encouragement and motivation to make it through the program. I appreciate help provided by Mr. Tao Ma in understanding technical aspects of 'Smart Tag' system.

I appreciate the support from the Nebraska Research Initiative for providing funding for this research. It is my pleasure to thank those who made this thesis possible which would not have been completed without the valuable contributions and advice of many people.

I am grateful to my parents, Mr. Megh Raj Dhakal and Mrs. Tara Dhakal, who persistently encouraged me in my mission with sincere compassion. Words of thanks will not be sufficient for their ultimate understanding patience and sacrifices. I am thankful to my brother, Mr. Kundan Dhakal, and sister-in-law, Mrs. Sonisa Sharma, for the guidance, love and encouragement.

Finally, I express my profound appreciation to Anita Panthi for her encouragement, understanding, and patience during my graduate program.

Table of Contents

Page No.

Appendices

List of Tables, Figures and Photographs

Tables

Figures

Photographs

Introduction

Worldwide outbreaks of dangerous livestock diseases such as bovine spongiform encephalopathy (BSE) or mad cow disease, scrapie, brucellosis, bovine tuberculosis, and avian influenza have increased concern about food safety and health status of animals and human beings. Caja et al. (2000) stated that "The global trade of live animals or animal products has dramatically increased the risks of human and animal disease outbreaks and makes difficult the traceability in food and feed chains." In many countries governments have mandated identification of individual animals to lessen the grave consequences of spread of such dangerous diseases. Disney et al. (2001) concluded that "Individual animal identification is an important consideration for many countries to improve animal traceback systems."

Discovery of cases of BSE or mad cow disease in North America and a confirmed BSE case in U.S. in December 2003 (Mathews et al., 2006), has intensified efforts to establish an animal identification program to protect animal and human health. In 2004, the U.S. Department of Agriculture (USDA) announced plans for universal tagging of livestock by utilization of radio frequency identification (RFID) technology and various databases (APHIS, 2009). The goal of the national animal identification system (NAIS) has been to track meat and dairy animals for several reasons including disease control, subsidy eligibility, quality and traceability assurance, and certification of animal health movement. This system would enable animal tracking from birth to eventual inclusion in the nation's food supply chain and would also help state and federal animal health officials to promptly ascertain status for issuing both intrastate and interstate animal health movement certificates (APHIS, 2009). Electronic tracking of animals using tags would greatly simplify this process. On the farm, information could be used to record for each animal growth rate, feed intake, health status and breeding history. Information on movement of animals could be stored to ensure that meat, and its history, could be traced back to an individual animal. Effective animal identification technology is needed for national and international programs to control dangerous animal and zoonotic diseases. Such technology could facilitate data-driven decision making by livestock producers regarding animal production management, food quality control, and animal health management.

The two most common methods of animal identification are passive and active RFID systems. With passive RFID, a small, non-powered tag with an identification number is usually attached to each animal and information is read by a reader device. The reader must be in close proximity to the tag, sometimes less than a foot to a maximum of a few feet. The range of RFID readers depends on transmission frequency and becomes more expensive as range increases. Stored information cannot be easily updated and, in most cases, the tag has to be replaced or brought very close to a programming (reader) device to add new information. Passive RFID has static information which may not meet the objectives of the NAIS plan for updating health information. Active RFID is a form of tagging technology which requires a battery pack for each tag. With active RFID, the communication range can be extended but would require a cumbersome battery pack which would create problems such as replacement issues, health risks from chafing, stress related to the weight and environmental hazards from the battery packs themselves. The functionality of active tags is limited because they do not support bidirectional communication links.

Until now, existing animal identification systems have not been self-powered and do not provide remote data "read"/ "write"/ "update" capabilities. They do not support a long distance range for each tag so the information can be remotely updated without removing the tag. The size and cost are not affordable for a tag small enough to be attached or implanted in the body of animal (where appropriate) without health risk. They do not support remote tracking, do not utilize an energy efficient bidirectional wireless communication protocol, and do not have integrated health monitoring sensors.

An animal identification system is needed to overcome these and other deficiencies in current animal identification systems. The prototype of a smart animal identification system ('Smart Tag') was developed at Advanced Telecommunications Engineering Laboratory (TEL) located in Omaha, Nebraska at the Peter Kiewit Institute, University of Nebraska, to meet the requirements set up by NAIS. The goals of this thesis were to do a distance coverage study of a prototype 'Smart Tag' and to do a cost-benefit analysis of 'Smart Tag' implementation.

Chapter 1. Review of literature

1.1 Animal identification

Animal identification dates back to ancient civilizations. Ancient civilizations attached much value to domesticated animals, especially horses (Blancou, 2001). Since the Neolithic period, animal identification techniques have been used by herders (Landais, 2001).

Caja et al. (2004) stated that "Different methods of marking animals were used by Egyptians, Greeks, Romans, nomadic people of Scandinavia, Asia and Africa, and Pre-Hispanic Americans for different purpose." Animal identification techniques such as giving names, tattooing and branding were used for centuries. Later ear tags made of either metal or plastic were used. More recently electronic identification systems which allow storing more information about an animal than just an identification number have been developed (Shulaw, 2010).

Livestock identification in the United States has been documented dating back to the late 1800's and early 1900's. Hot iron branding was and is still used by cattle ranchers to indicate ownership and deter theft (APHIS, 2009). Richey et al. (2005) indicated that livestock identification became more important for tracking diseased animals after outbreaks of rabies and tuberculosis near the end of World War I (WWI). One of the first identification systems was ear tagging of cattle for the federal tuberculosis eradication program, which was initiated shortly after WWI (Doby, 1977). In the early 1960s, APHIS began using ear tags, back tags, tattoos and face brands. Metal ear tags later became the standard form of identification. Eventually automated identification systems were used as a way to help producers manage and record data for large herds of livestock (Rossing, 1999). These identification methods were required by statutory regulations and were successfully used to trace movements of diseased animals during disease outbreaks and in eradication programs, including those for brucellosis and hog cholera (APHIS, 2009).

After a case of bovine spongiform encephalopathy (BSE) on December 23, 2003 demonstrated the need of a national identification and traceability system for animals. In April of 2004, the U.S. Department of Agriculture (USDA) announced plans for universal tagging of livestock in the nation with utilization of radio frequency identification (RFID) technology and with implementation of various databases (APHIS, 2009).

The purpose of the national animal identification system (NAIS) is to track meat and dairy animals for several reasons including disease control, subsidy eligibility, quality and traceability assurance, and certification of animal health movement. This system would enable animal tracking from birth to eventual inclusion in the nation's food supply chain (APHIS, 2009). The NAIS would also allow public health officials to trace animals through the processing chain and help to prevent consumption of products that were exposed to disease or harmful pathogens (Vitiello and Thaler, 2001). Holland and Bruch (2010) stated that interest in a national identification system has surged for at least two significant reasons: the need for immediate response and follow-up to major livestock disease outbreaks and increased availability of technologically advanced identification systems.

Regulations and requirements of food safety and systems for tracing animal identification have recently become controversial, and will likely continue to be debated in the coming years but these issues should be addressed immediately.

Increased awareness of food-related safety issues among food consumers, coupled with a more educated public, is driving the demand for more information about the food supply chain and specifically, the origin and handling of basic commodities and food products generated and consumed throughout the world (Sparks, 2002). According to Golan et al. (2004), US private sector food firms are developing, implementing and maintaining substantial traceability systems designed to (a) improve food supply management, (b) facilitate traceback for food safety and quality, and (c) differentiate and market foods with subtle or undetectable quality attributes. International concerns for traceback systems have increased due to outbreaks of diseases such as avian influenza, swine influenza, BSE, and foot and mouth disease.

Tonsor and Schroeder (2006) claimed that animal identification in the livestock sector is gaining popularity among producers who are looking for strategies to 1) increase consumer confidence through improved food safety and traceability, 2) improve management tools, 3) increase international trade, and 4) ease concerns regarding animal health and bio terrorism. Animal identification is needed for early detection of disease and rapid animal tracing (Pendell, 2006). Pendell (2006) reported that early detection of FMD in 2001 and rapid animal tracing in the United Kingdom would have limited the disease spread.

The USDA has proposed the use of the latest technology to electronically record and trace livestock records with high-tech digital computer systems (Ishmael, 2006). Electronic identification methods including bar codes and/or radio frequency identification (RFID) transponders are becoming increasingly useful tools for herd management (APHIS, 2009). Electronic RFID tags can store information. Wands or electronic readers can retrieve data from the tag (Ishmael, 2006). The RFID tags have an identification number engraved with a laser on the outside of the tag, which corresponds to the International Standards Organization (ISO) number programmed on the RFID tag (Mennecke and Townsend, 2005).

The current primary driving forces behind the development of livestock identification systems are based on recognized industry needs (APHIS, 2009). The needs include disease control and eradication, disease surveillance and monitoring, plans for emergency response to foreign animal diseases, livestock production efficiency, consumer concerns over food safety, and emergency management programs (APHIS, 2009).

1.2 Electronic identification systems

Stonehouse (1978) stated that "Despite the key role of electronic identification in the retail industry for over 50 yrs, its use in animals was not explored until 1970s." The first applications of electronic identification were to monitor behavior of wildlife (Cochran, 1980). In the early 1970s, research institutes in different countries developed the first electronic animal identification systems which were built with conventional components and attached to a collar around the cow's neck (Rossing, 1999). These early devices were large, awkward, susceptible to damage, expensive, and not suited to livestock (McAllister et al., 2000). These early systems are categorized as first generation electronic 'black boxes'. Later, further miniaturization of electronics (second generation) allowed development of tiny electronic transponders which could be injected under the skin. The third generation, currently under development, includes read/write possibilities and sensor technologies for automatic monitoring of animal health and performance (Eradus and Jansen, 1999).

Electronic identification systems have great performance potential at this time as they can be used not only for process control on farms, but can also be implemented for control tasks such as animal disease monitoring (Artmann, 1999). In addition to animal identification, other practical uses of electronic identification systems include identification for feeding, weighing, milk yield recording, monitoring of animal health, and meat inspection (Lambooij, 1991). The ability of electronic identification systems to interface readily with computers enables compilation of data for an information network that can be used in management, extension, regulation, health, trade, processing and consumer decisions (McAllister et al., 2000).

Geers et al. (1997) defined the components of an electronic identification system as: “(i) a device that contains a unique identification number associated with an animal; (ii) an activation reading device that initiates communication and interprets the code; (iii) software which compiles and collates identification codes with other collected information”.

Fallon et al. (2002) reported that some options available for electronic identification of an animal are an electronic button tag in the ear, an implantable electronic chip in the ear-base, and an electronic rumen bolus placed in the rumen/reticulum by the esophageal route. Use of an electronic rumen bolus showed some good results. The heavy electronic rumen boluses, however, were more expensive than either an injectable transponder or an electronic ear tag. An animal with a rumen bolus would require external identification for routine management.

Recovery of the bolus post slaughter is more problematic than removal of an electronic ear tag (Fallon et al. 2002).

Electronic identification systems most implemented in livestock are bar code systems and RFID systems (Finkenzeller, 2003). McAllister et al. (2000) found that bar codes are frequently damaged under practical production conditions and that debris on the tag surface as well as changing light conditions can substantially reduce read success.

Although, RFID has been in existence since the 1940s, only in recent years due to technological advancements has RFID been able to compete with barcodes on price, performance and size. In addition, RFID devices with data storage capacities comparable with barcodes could be used for a totally automatic record creation system (Watts et al., 2002). RFID has gained significant acceptance for object identification in various supply chains (Ng et al., 2005) and has also been applied to the livestock farming industry for disease control, breeding management and stock management (Finkenzeller, 2003).

1.3 RFID systems

RFID is a generic term used to describe a system that transmits the identity (in the form of a unique identification number) of an object or person wirelessly, using radio waves (RFID Journal, 2005). An RFID system consists of tags, one or more readers (or interrogators) and a network system for data handling (Ng et al., 2005). In a RFID system, data are stored in an electronic data carrying device – the transponder. The purpose of the transponder is to reply to an interrogation request received by a reader, mainly by returning data stored in transponder memory such as an identity code or the value of a measurement (Popa et al., 2004). A block diagram of an RFID system is depicted in Figure 1.

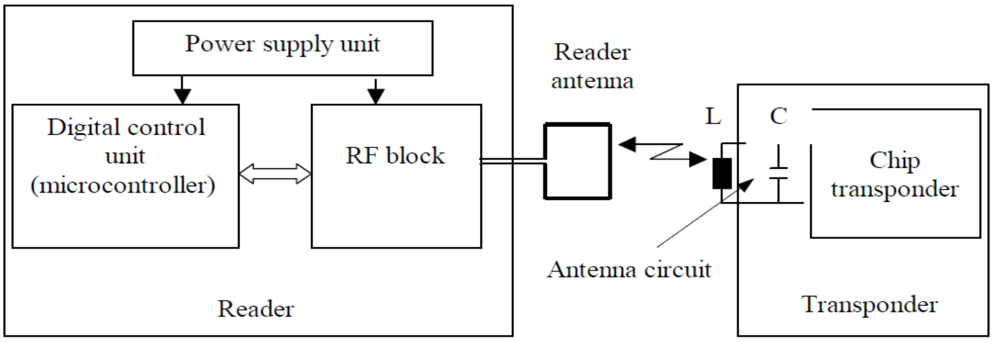

Figure 1. Block diagram of a RFID system (Popa et al., 2004).

The reader can be a read or a read/write device, depending upon the design and technology. The transponder unit is composed of a chip transponder and an antenna circuit (a coil, L, and a capacitor, C,). The capacitor can be an internal capacitor, an external capacitor or a combination of these two. In all variants, the design will also include in C the parasitic capacitance. All transponder functions are controlled by the reader.

1.3.1 Types of RFID tags

Basically there are three types of tag available commercially based on power sources, i.e., active, semi-passive and passive. Active tags have their own source of power, such as a battery, and may initiate communication with a reader or might even form ad-hoc peer networks with other active tags (Weis, 2006). Because they contain their own power source, active tags typically have a much greater operating range than passive tags and are often used in livestock tracking applications. Semi-passive tags have an internal battery but are unable to initiate communication and are active only when queried by a reader (Weis, 2006). Passive tags have neither their own power source, nor the ability to initiate communication. They often obtain energy by harvesting it from an incoming RF communication signal (Weis, 2006).

Tags can be also classified as read-only or read/write. According to Mennecke and Townsend (2005), read only tags are preset to a specific identification number and will retain that information throughout their life, whereas read/write tags can be written to by an appropriate read/write device. Writeable tags would allow full information about an animal's health and feed data and its recent transportation history to be stored so that processors would not have to access any outside database to extract the animal's relevant information.

Different RFID systems operate at a variety of radio frequencies (Weis, 2006). Different types of standard frequencies and their respective passive read distances are listed Table 1.

Table 1. Common RFID operating frequencies (Weis, 2006)

Frequency Range	Frequencies	Passive Read Distance
Low Frequency (LF)	120-140 KHz	10-20 cm
High Frequency (HF)	13.56 MHz	10-20 cm
Ultra –High Frequency (UHF)	868 – 928 MHz	3 meters
Microwave	2.45 and 5.8 GHz	3 meters
Ultra-Wide Band (UWB)	3.1 – 10.6 GHz	10 meters

Ng et al. (2005) proposed the use of UHF tags for livestock identification due to their read range and ability to support transmission. LF tags can be read only at close range and may not perform well when multiple tags are simultaneously present in the interrogation field. However, RFID tags presently used in the livestock industry are LF tags that are read at a radio frequency of 134.2 KHz (Walker and Vaith, 2006). LF tags are able to be read through non-metallic substances and are ideal for scanning objects with high water content at close range (Mennecke and Townsend, 2005). These tags are most appropriate for use with meat products, particularly where the tag might have meat between it and a reader.

In the livestock industry, the four common placements of a RFID used for animal identification are – attaching a transponder to the collar, attaching a transponder to an ear tag, injecting tiny glass transponders under the animal's skin, and via a 'bolus' where the RFID transponder is mounted within an acid resistant, cylindrical housing which is inserted permanently within an animals' stomach, i.e., rumen boluses (Finkenzeller, 1999; Walker and Vaith, 2006).

1.4 Wireless sensor networks

Wireless sensor network (WSN) technology has advanced rapidly in recent years. Zigbee and Bluetooth technologies are used in WSN technology (Ruiz-Garcia et al., 2009). Sensor networks are capable of monitoring a wide variety of ambient conditions such as temperature, humidity, vehicular movement, light conditions, pressure, soil makeup, noise levels, and presence or absence of certain kind of objects (Estrin et al., 1999). Sensor nodes can be used for continuous sensing, event detection, event identification, and location sensing and actuators (Akyildiz et al., 2002).

The main difference between a WSN and a RFID system is that RFID devices have no cooperative capabilities, while WSN devices allow different network topologies and multihop communication (Ruiz-Garcia et al., 2009). Other major differences between WSN and RFID system are summarized in Table 2.

Table 2. Comparison of WSN and RFID systems (Liu et al., 2008)

Attribute	Wireless sensor network (WSN)	RFID Systems
Purpose	Sense parameters in the environment or provide information on the condition of attached objects	Detect presence of tagged objects
Component	Sensor nodes, relay nodes , sinks	Tags, Readers
Protocols	Zigbee, Wi-Fi	RFID Standards
Communication	Multihop	Single-hop
Mobility	Sensor nodes are usually static	Tags move with attached objects
Power Supply	Battery powered	Tags are battery powered or passive
Programmability	Programmable	Usually closed systems
Price	Sensor node – medium Sink – expensive	Reader – expensive Tag – cheap
Deployment	Random or fixed	Fixed, usually requires careful placements
Design Goal	WSNs are for general purpose	Tags are optimized to perform a single operation, such as read

Deployment of wireless sensors and sensor networks in agriculture and the food industry is still in the beginning stage (Wang et al., 2006). Wireless sensor technologies have been used with wild animals to monitor their habitat and for tracking (Mainwaring et al., 2002). WSN has been used as a way to measure core body temperature that is minimally invasive and that provides continuous, remote, real-time information (Ruiz-Garcia et al., 2009).

Mayer et al. (2004) created a WSN platform for animal health and behavior monitoring. A steer is fitted with both internal and external sensors, using matchbox sized motes placed inside standard drug release capsules. The nodes are used to monitor intra-ruminal activity and to communicate wirelessly with other nodes.

Nagl et al. (2003) designed a remote health-monitoring system for cattle that incorporated various sensors, including a global positioning system (GPS) unit, a pulse oximeter, a core body temperature sensor, an electronic belt, a respiration transducer and an ambient temperature transducer. The system was able to communicate wirelessly with a base station via Bluetooth telemetry. Brown-Brandl et al. (2001) tested a short-range telemetry system for measuring core body temperatures in poultry, beef and dairy cattle. Temperature transmitters were implanted into the body. A CorTempTM miniaturized ambulatory logger received the temperature data wirelessly. Test results showed good accuracy, resolution, and response time for temperature measurement. Marsh et al. (2008) implanted an injectable RFID and temperature sensor into the neck of a horse to measure body temperature.

Ipema et al. (2008) demonstrated that capsule-based wireless technology (i.e., a temperature sensor built into a bolus placed in the rumen of a cow) can be used to monitor temperature. The sensor node in the rumen transmitted data to the sensor node attached to the front leg of the cow; from there the signal was transmitted to the base station. Darr and Zhao (2008) developed a wireless data acquisition system for monitoring temperature variation in swine barns.

1.5 Health sensors

Temperature, ruminal pH and pulse sensors for animal health monitoring are currently available.

1.5.1 Temperature monitoring

Nakamura et al. (1983) defined body temperature as the "single most useful measurable parameter and a sensitive indicator of the reactions of the animal to physical environmental factors, disease processes, and physiological functions such as nutrition, lactation, and reproduction." Opasjumruskit et al. (2006) stated that a read-only RFID sensor, Bio-Thermo, was designed for an animal healthcare application which comes in an implantable glass-tube form and uses a 134.2 kHz carrier frequency. The protocol conforms to the animal identification standard (ISO 11785). It does not however, provide memory space to store user data.

The DestronLifechip with Bio-Thermo™ RFID implanted in the nucal ligament of a horse proved promising to measure body temperature. It provided a measure of body temperature similar to the measure of rectal temperature with a digital thermometer (Wallace et al., 2008). According to Nagl et al. (2003), the CorTemp system from HQInc which consists of an ingestible bolus (the bolus houses a temperature sensor, low-power RF transmitter, and power source capable of providing up to nine months of power) and a receiver unit is a good temperature monitoring system for livestock.

Many US patents have been filed for temperature monitoring systems used for livestock. A short summary of some of them has been prepared by Guice and Thompson (2002) in their patent application:

" ….. U.S. Pat. No. 3781837 describes a temperature-measuring device which is installed into a cow's ear and held on by straps. This device required temperature compensation in order to monitor animal temperature relative to ambient temperature, but provided no means for sending an alert to central control point, which is important for large scale production operations. U.S. Pat. No. 3899111 describes an apparatus and method for remotely monitoring an animal's temperature, but does not describe a practical approach for scaling the method to large-scale operations such as commercial feedlots. U.S. Pat. No. 4844076 describes an ingestible continuously transmitting temperature monitoring pill. However, the range for this device is not practical for use in large-scale commercial operations, nor does it have any features for conserving battery life for long-term operation. U.S. Pat. No. 4854328 describes an implantable temperature monitoring electronic capsule with a small low power transmitter. However, the range of this device is limited and requires a receiver attached to the animal. Although this patent discloses the use of a relay device for increased range, no means are provided to avoid collisions between simultaneous transmissions from multiple animals, and no features are described to achieve the long battery lifetime required for commercial feedlot operations. U.S. Pat. No. 4865044 discloses a temperature sensing system for cattle that used a transmitter and encoding circuitry mounted on ear tag connected by wire to a temperature-sensing probe located in the ear canal of the animal being monitored. Although this system has value in monitoring temperature of animals in research or small volume operations, there will likely be problems with installation time and with retention of the wired probe in the ear canal when this system is used in large-scale commercial applications. U.S. Pat. Nos. 5984875, 6059,733 and 6099,482 describe an animal temperature sensor system that uses ingestible boluses for monitoring physiological parameters of animals. Although the size of these boluses provides for a longer battery life, and the boluses contain an RF transmission capability, they present a risk related to contamination of food products if they are not located and recovered during slaughter and processing of food animals."

Guice and Thompson (2002) in their patent application claimed that temperature monitoring can be done precisely in livestock via their automated animal health monitoring system which includes implantable wireless "smart tele-sensor" elements that can be implanted within the animal to measure temperature. A sensor-modulator based in tunnel diode (implanted) was used successfully to monitor temperature in rat and humans (Villamar and Suaste, 2003). Ipema et al. (2008) used a rumen bolus containing a mote (temperature sensor, processor and radio) to monitor body temperature in the rumen of fistulated dairy cows. Ingestible pills for heart rate and core temperature measurement in cattle were developed by Martinez et al. (2006).

1.5.2 Rumen pH

Subacute ruminal acidosis (SARA) characterized by periods of low ruminal pH, depressed feed intake, and subsequent health problem is a major metabolic disorder in ruminants. A record of the pH of ruminal fluid would help to manage this disorder. AlZahal et al. (2007) proposed a system for continuous recording of ruminal pH in cattle. The continuous recording system was composed of two main components; an indwelling pH electrode (PHE-7352-6-PT100, Omega Engineering

Inc., Stamford, CT) and a portable data logger (pHTemp101, Monarch Instrument, Amherst, NH).

Mottram et al. (2008) developed a wireless telemetric method of monitoring clinical acidosis in dairy cows. They used a rumen bolus consisting of a pH sensor with the reference cell being a gell-filled annular space around a glass electrode bulb with the reference junction being porous teflon (Fig. 2), a radio transceiver, an aerial and a battery. All components are sealed within an enclosed container small enough to pass down the throat of an animal.

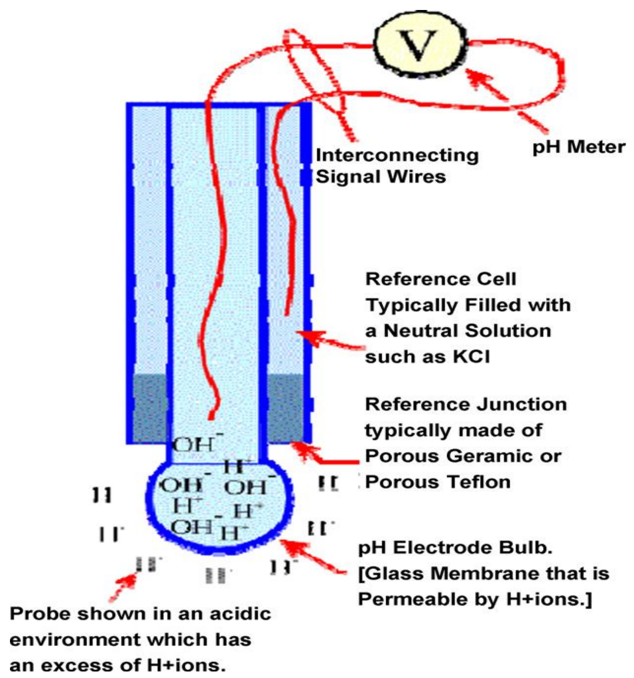

Figure 2. Diagram of pH sensor (Mottram et al., 2008)

1.5.3 Pulse oximetry

Pulse oximetry was introduced in 1983 as a non-invasive method for monitoring arterial blood oxygen saturation which was easy to use, readily available, and accurate. The wearable system can supply information about blood oxygen saturation, heart rate and pulse amplitude (Bonfiglo and Rossi, 2010). According to Webster (1997) pulse oximetry designed for human beings works in the following way:

1. "The light absorbance of oxygenated haemoglobin and deoxygenated haemoglobin at the two wavelengths is different. To be more precise, the set of associated extinction coefficients for the absorption of light for these wavelengths is linearly independent with great enough variation for adequate sensitivity but not so large that the blood appears opaque to either of the light sources. This model assumes that only oxygenated and deoxygenated haemoglobin are present in the blood.

2. The pulsatile nature of arterial blood results in a waveform in the transmitted signal that allows the absorbance effects of arterial blood to be identified from those of non-pulsatile venous blood and other body tissue. By using a quotient of the two effects at different wavelengths, it is possible to obtain a measure requiring no absolute calibration with respect to overall tissue absorbance. This is a clear advantage of pulse oximeters over previous types of oximeters.

3. With adequate light, scattering in blood and tissue will illuminate sufficient arterial blood, allowing reliable detection of the pulsatile signal. The scattering effect necessitates empirical calibration of the pulse oximeter. On the other hand, this effect allows a transmittance path around bone in the finger."

Nagl et al. (2003) successfully tested a pulse oximeter for cattle.

1.6 RFID costs and benefits

Coffey et al. (2005) estimated that U.S. beef industry losses caused by export restrictions during 2004 ranged from \$3.2 billion to \$4. 7 billion due to discovery of a single dairy cow infected with BSE in the United States in December 2003. Pendell et al. (2010) stated that "An effective animal identification and tracking system might reduce such adverse economic impacts of restricted market access resulting from an animal health or food safety event if the system could rapidly trace, isolate, and mitigate a disease outbreak." For example, animal identification and traceability systems can significantly reduce the duration of an outbreak, the rate of spread, and economic consequences of a highly contagious foreign animal disease (Saatkamp et al., 1995, 1997). Diseases other than BSE, including brucellosis and FMD, may be of equal or even more concern. The ability to track animal movement and interaction would provide a critical tool for animal health professionals in controlling and potentially eradicating these diseases (Bailey, 2004).

Trevarthen and Michael (2000) concluded that "RFID is currently being deployed in government mandated livestock identification schemes across the world.

RFID in its basic function can help authorities identify animals, especially when traceability becomes paramount during disease outbreaks across regions."

Blasi et al. (2003) estimated costs of implementing a RFID system at the producer level for cow/calf operators and feedlots. Costs of transponder tags, electronic readers, computer hardware, computer software, internet access, required upgrades and labor were included (Tables 3 and 4).

Table 3. Estimated annual costs for a RFID system for cow/ calf operations of different herd sizes (n) (Blasi et al., 2003)

Herd Sizes (n)	Total estimated annual cost/cow ($)
63	$ 24.49
125	$13.78
188	$10.14
250	$8.34
625	$5.08
938	$4.35
1250	$3.99

Table 4. Estimated annual costs for a RFID system for feedlot operations of different herd sizes (n) (Blasi et al., 2003)

Herd sizes (n)	Total estimated annual cost/animal
2,500	$5.40
5,000	$3.61
10,000	$2.72
15,000	$2.42
20,000	$2.27
35,000	$2.08
50,000	$2.00

1.7 Conclusions

Animal ear tags are currently the most common method of identifying individual animals. Electronic ear tags such as RFID tags are becoming popular among farmers and producers. NAIS is likely to require mandatory animal identification to track all animals from farm to fork in the near future. Despite the increasing number of RFID ear tag technologies, these technologies do not meet the standards set up by USDA for NAIS. Studies have shown that farmers are interested in using sensors to monitor the health status of their animals. Few companies make sensor based systems that can monitor health status of animal.

Literature cited

Akyildiz, I. F., W. Su, Y. Sankarasubramaniam and E. Cayirci. 2002. Wireless sensor networks: a survey, Computer Networks 38 (4): 393–422.

AlZahal, O., B. Rustomo, E.N. Odongo, F.T. Duffield, and W. B. McBride. 2007. Technical note: A system for continuous recording of ruminal pH in cattle. J Anim Sci 2007.85:213-217.

APHIS USDA Veterinary Services. 2009. History of animal identification. Accessed Aug. 28, 2009. http://www.aphis.usda.gov/animal_health/animal_diseases/animal_id .

Artmann, R. 1999. Electronic identification systems: state of the art and their further development. Computers and Electronics in Agriculture, 24(1): 5-26.

Bailey, D. 2004. Animal identification: Benefits and costs associated with an animal identification system for cattle in the United States. Western extension marketing committee 2, No. 04.

Blancou, J. 2001. A history of the traceability of animals and animal products. Revue Scientifique et Technique, 20(2): 413-425.

Blasi, D. A., K.C. Dhuyvetter, M.F. Spire, M. P. Epp, and B. Barnhardt. 2003. A guide for electronic identification of cattle. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Bonfiglio, A., and D. D. Rossi. 2010. Wearable monitoring systems. Springer Science + Business Media, LLC, 233 Spring Street, New York, NY 10013, USA.

Brown-Brandl, T.M., T. Yanagi, H. Xin, R.S. Gates, R. Bucklin, and G. Ross. 2001. Telemetry system for measuring core body temperature in livestock and poultry. ASAE Paper No.: 01-4032. The American Society of Agriculture Engineers, St. Joseph, Michigan, USA.

Caja, G., J. J. Ghirardi, M. Herna´ndez-Jover, and D. Garı´n. 2004. Diversity of animal identification techniques: From 'fire age' to 'electronic age'. Pages 21–41 in Seminar on development of animal identification and recording systems for developing countries. R. Pauw, S. Mack, and J. Ma¨ki-Hokkonen, ed. ICAR Technical Series No. 9, Rome, Italy.

Cochran, W. W. 1980. Wildlife telemetry. In S. D. Schemnitz, ed. Wildlife Management Techniques Manual. 4th ed. Wildlife Society, Washington, DC. : 507–520.

Coffey, B., J. Mintert, S. Fox,T. Schroeder, and L. Valentine. 2005. The economic impact of BSE on the U.S. beef industry: Product value losses, regulatory costs, and consumer reactions. Kansas State University Agricultural Experimental Station and Cooperative Extension. Serial no.MF- 2678.

Darr, M.J., and L. Zhao. 2008. A wireless data acquisition system for monitoring temperature variations in swine barns. In Livestock Environment VIII. ASABE eighth international symposium, Iguassu Falls, Brazil.

Disney, W.T., J. W. Green, K.W. Forsythe, J.F. Wiemers, and S. Weber. 2001. Benefit-cost analysis of animal identification for disease prevention and control. Rev. Sci. et Techique de l'Office Internacional des Epizooties 20 (2001):385-405.

Doby, P. B. 1977. Identification of Hogs and Cattle – Is it still needed? Official proceedings of the livestock conservation institute. Australia.

Eradus, W. J., and M. B. Jansen. 1999. Animal identification and monitoring. Computers and Electronics in Agriculture, 24(1): 91-98.

Estrin, D., R. Govindan, J. Heidemann, and S. Kumar. 1999. Next century challenges: scalable coordination in sensor networks, ACM MobiCom'99, Washington, USA, : 263-270.

Fallon, R., P. Rogers, and B. Earley. 2002. Electronic animal identification. End of project report ARMIS No. 4623, Teagasc, The Irish agriculture and food development authority, Grange research centre, Dunsany, Co. Meath, Ireland.

Finkenezeller, K. 2003. RFID Handbook : Fundamentals and applications in contactless smart cards and identifications, 2nd edition. UK.

Finkenzeller, K. 1999. RFID Handbook: Radio-Frequency Identification Fundamentals and Applications, John Wiley & Son, UK.

Geers, R., B. Puers, V. Goedseels, and P. Wouters. 1997. Electronic identification, monitoring and tracking of animals. CAB International, Wallingford, Oxon, UK. 156 pp.

Golan, E., B. Krissoff, F. Kuchler, L. Calvin, K. Nelson, and G. Price. 2004. Traceability in the US food supply: Economic theory and industry studies. Agricultural economic report number 830, Economic research service, US Department of Agriculture, Washington, DC.

Guice, L. D., and A. N. Thompson. 2002. Method and system for monitoring the health and status of livestock and other animals. United States Patent Application Publication.

Haapala, H.E.S. 2003. Operation of electronic identification of cattle in Finland. In: proceedings of 4th European conference in precision agriculture, Berlin, Germany, June 14-19.

Holland, R., and M. Bruch. 2010. A sampling of thoughts on electronic identification and other information from cattle producers. Electronic identification. UT Extension. Accessed Jan. 7, 2011.http://utextension.tennessee.edu/publications/Documents/W053.pdf.

Ipema, A.H., D. Goense, P.H. Hogewerf, H.W.J. Houwers, and H. van Roest. 2008. Pilot study to monitor body temperature of dairy cows with rumen bolus. Computers and Electronics in Agriculture 64: 49-52.

Ishmael, W. 2006. National animal ID is here…sort of. Shorthorn Country, 4(6): 16–20.

Lambooij, E. 1991. Automatic electronic identification systems for farm animals. In: Automatic electronic identification systems for farm animals. Proceedings of a seminar held in Brussels, Belgium , 17-19 October, 1990, No. 13198, 21-27.

Landais, E. 2001. Revue scientifique et technique del office international des epizooties 20: 463-479.

Liu, H., M. Bolic, A. Nayak, and I. Stojmenovic. 2008. "Taxonomy and challenges of the integration of RFID and wireless sensor networks," in IEEE Network,26–35.

Mainwaring, A., R. Szewczyk, D. Culler, and J. Anderson. 2002. Wireless sensor networks for habitat monitoring. In Proceedings of ACM WSNA'02, September.USA.

Marsh, J.R., R.S. Gates, G.B.Day, G.E. Aiken, and E.G Wilkerson. 2008. Assessment of an injectable RFID temperature sensor for indication of horse well-being. In ASABE annual international meeting 2008, Providence, Rhode Island, USA.

Martinez, A., S. Schoeing, D. Andresen, and S. Warren. 2006. Ingestible pill for heart rate and core temperature measurement in cattle. Proceedings of the 28th IEEE EMBS annual international conference , USA.

Mathews, K.H. Jr, M. Vandeveer, and R.A. Gustafson. 2006. An economic chronology of bovine spongiform encephalopathy in North America. Economic research service, U.S. Department of Agriculture, Washington, DC.

Mayer, K., K. Ellis, and K. Taylor. 2004. Cattle health monitoring using wireless sensor networks. In proceedings of the communication and computer networks conference (CCN 2004), Cambridge, MA, USA.

McAllister, T. A., D. J. Gibb, R.A. Kemp, C. Huisma, M. E. Olson, D. Milligan, and K.S. Schwartzkopf-Genswein. 2000. Electronic identification: Applications in beef production and research. Can. J. Anim. Sci. 80: 381–392.

Mennecke, B., and A. Townsend. 2005. Midwest agribusiness trade research and information center. Radio frequency identification tagging as a mechanism of creating a viable producer's brand in the cattle industry. Accessed Jan. 13, 2011. http://www.card.iastate.edu/publications/DBS/PDFFiles/05mrp8.pdf.

Mottram, T., J. Lowe, M. McGowan, and N. Phillips. 2008. Technical note: A wireless telemetric method of monitoring clinical acidosis in dairy cows. Computers and electronics in agriculture. 64: 45-48.

Nagl, L., R. Schmitz, S. Warren, T. S. Hildreth, H. Erickson, and D. Andresen. 2003. Wearable sensor system for wireless state-of-health determination in cattle. In: Proceedings of the 25th IEEE EMBS Conference, Cancun, Mexico, September 17–21.

Nakamura, R.M., T. C. Araki, N.L. Clarke , and G.W.L. Kam . 1983. Temperature telemetry studies in dairy cattle in hot climates. National conference on agricultural electronics applications. american society of agricultural engineers, Chicago, Illinois. pp: 464-469.

Ng, M.L., K. S. Leong, D. M . Hall, and P.H. Cole. 2005. A simple passive UHF RFID tag for livestock identification. In: Proceedings of IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communication, pp. 67–70.

Opasjumruskit, K., T. Thanthipwan, O. Sathusen, P. Sirinamarattana, P. Gadmanee, E. Pootarapan, N. Wongkomet, A. Thanachayanont, and M. Thamsirianunt. 2006. Self-powered wireless temperature sensors exploit RFID technology. IEEE Pervasive Computing Magazine, January-March 2006 (Vol. 5, No. 1) pp. 54-61.

Pendell, D.L. 2006. Value of animal traceability systems in managing a foot-and-mouth disease outbreak in southwest Kansas. Ph.D. dissertation. Kansas State University.

Pendell, D.L., G.W. Grester, T.C. Schroeder, K.C. Dhuyvetter, and G.T. Tonsor. 2010. Animal identification and tracing in the United States. American journal of agricultural economics 92 :927-940.

Popa, V., T. Strugariu, C. Siicu, and E. Coca. 2004 . Livestock RF identification and management. Part I: 13,56 MHz rfid system. 7^{th} International Conference on development and application systems. Suceava, Romania, May 27-29.

RFID Journal. 2005 . What is RFID? Accessed Jan. 13, 2011. http://www.rfidjournal.com/article/articleview/1339/1/129/.

Richey, B. D., G. N. Slack, and M. Vise-Brown. 2005. Animal agriculture and identification: Historical significance. Prepared by National Institute for Animal Agriculture for U.S. Veterinarian 2005.

Rossing, W.1999. Animal identification: Introduction and history. Computers and Electronics in Agriculture, 24(1): 1-4.

Ruiz-Garcia, L., L. Lunadei, P. Barreiro, and I. Robla. 2009. A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends. Sensors 9: 4728–4750.

Saatkamp, H. W., A. A. Dijkhuizen, R. Geers, R. B. Huirne, J. P. Noordhuizen, and V. Goedseels. 1997. Economic evaluation of national identification and recording systems for pigs in Belgium. Preventive veterinary medicine 30: 121–135.

Saatkamp, H.W., R. Geers, J. P. Noordhuizen, A. A. Dijkhuizen, R. B. Huirne, and V. Goedseels. 1995. National identification and recording systems for contagious animal disease control. Livestock production science 43: 253–264.

Shulaw, W. 2010. Livestock identification, traceability, & the future of BTB control. CattleNetwork latest news. Drovers CattleNetwork. Accessed Dec. 20, 2010. http://www.cattlenetwork.com/Livestock-Identification--Traceability----The-Future-Of-bTB-Control/2010-09-22/Article.aspx?oid=1243659&fid=CN-LATEST_NEWS_.

Sparks. 2002. Food traceability: Standards and systems for tracing and tracking food and agri-products. Sparks Companies, Inc. Memphis, TN

Stonehouse, B. 1978. Animal marking - recognition marking of animals in research. 1st ed. Macmillian Press, London, UK. pp 257.

Tonsor, G. T. and T. C. Schroeder. 2006. Livestock identification: Lessons for the US beef industry from the Australian system. J. Int. Food Agribusiness Marketing 18:103-118.

Villamar, A. L., and E. Suaste. 2003. Tunnel diode oscillator applied as sensor-modulator for telemetry of temperature in human beings and animals. Proceedings of the 25th Annual International Conference of the IEEE EMBS Cancun, Mexico.

Vitiello, D. J., and A. M. Thaler. 2001. Animal identification: Links to food safety. Revue Scientifique et Technique. L'Office International des Epizooties., 20(2): 598-604.

Walker, J., and K. Vaith . 2006. Radio frequency identification for beef cattle. Accessed Jan. 13, 2011. http://www.thebeefsite.com/articles/821/radio-frequency-identification-for-beef-cattle.

Wallace , L.E., J.A. Paterson, L. Gagnon, R. Clark, K. Davis, and M. Miller. 2008. Evaluation of implantable RFID mircochips for readability and measurement of body temperature in mature horses. Proceedings, Western Section, American Society of Animal Science. Vol. 59.

Wang, N., N.Q. Zhang, and M.H. Wang. 2006. Wireless sensors in agriculture and food industry – Recent development and future perspective. Computer and electronics in agriculture. 50: 1-14.

Watts, A., P. Miller, and D. Godwin. 2002. Applications of RFID in agriculture. Pesticide outlook, 13: 254-258.

Webster, J.G. 1997. Design of pulse oximeters. Taylor and Francis, London.

Weis, A. S. 2006. RFID: Principles and Applications. Accessed Jan. 13, 2011. http://www.eecs.harvard.edu/cs199r/readings/rfid-article.pdf.

Chapter 2. Distance coverage study of a 'Smart Tag'.

2.1 Introduction

There has been an increase in use of passive and active radio frequency identification (RFID) tags for animal identification purposes. Both passive and active RFID tags seem promising when used in close proximity (less than a meter) to a tag reader. However, their distance performance becomes poorer as distance increases. Long distance coverage for animal identification and monitoring may be very important to the livestock industry for making animal management decisions and to better understand livestock behavior, grazing habits, and interactions with the surrounding environment (Wark et al., 2007). Wireless sensor network (WSN) technology can not only provide coverage over long distances but is promising for monitoring physical or environmental conditions, such as temperature, sound, vibration, pressure, motion and pollutants (Akyildiz et al., 2002).

Baggio (2005) stated that developments in the field of WSNs have allowed precision agriculture to be adopted by the agriculture sector. The first major use of WSNs with animals was for tracking zebras as a part of the ZebraNet Project (Zhang et al., 2004). This system provided animal global positioning system (GPS) position data taken every few minutes to be transmitted in a peer-to-peer fashion to other animals when within range. Researchers have since proposed more sophisticated systems for ad-hoc routing of data through large networks of mobile cattle nodes (e.g., Radenkovic and Wietrzyk, 2006).

Outbreaks of dangerous diseases such as bovine spongiform encephalopathy (BSE) or mad cow disease in the cattle herds of North America and a confirmed BSE cow in U.S. in December 2003 (Mathews et al., 2006), led to intensified efforts to establish an animal identification program to protect animal and human health. Davis (2002) reported that nationwide cattle monitoring has been identified as an important means of detecting outbreaks of these dangerous diseases and is potentially able to save large amounts of money. Animals tags based on WSNs technology with health monitoring sensors could be one option for providing accurate animal identification and tracking.

A prototype of a smart animal identification system ('Smart Tag') based on WSNs technology was developed at the Advanced Telecommunications Engineering Laboratory (TEL) located in Omaha, Nebraska at the Peter Kiewit Institute, University of Nebraska. The objective of this study was to evaluate distance coverage performance of a prototype of the 'Smart Tag'.

2.2 Material and methods

A prototype of 'Smart Tag' (Photo 1) based on WSNs technology was designed and developed at the Computer and Electronics Engineering (CEEN) Department, Advanced Telecommunications Engineering Laboratory (TEL) located at the Peter Kiewit Institute, University of Nebraska. The 'Smart Tag' operates within the Industrial Scientific and Medical (ISM) band of 2.4 GHz, which is license free, has a large spectrum allocation and has worldwide compatibility.

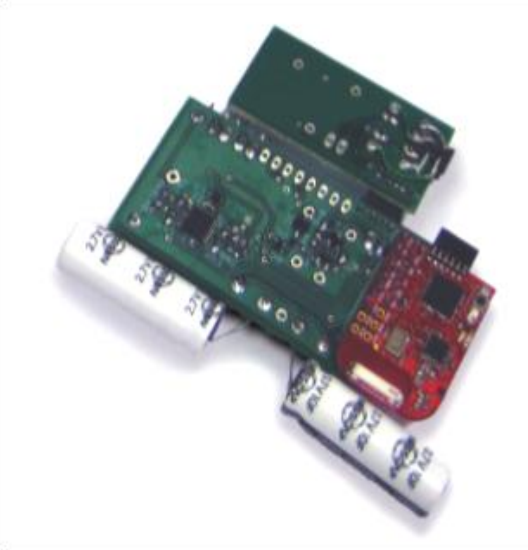

Photo 1. A prototype of 'Smart Tag'.

Photo 2. A receiver.

This novel 'Smart Tag' is a self-powered device capable of complete animal identification and tracking. Energy for signal transmission and operating of the tag is provided by solar energy (Fig. 3). The tag also integrates sensors to monitor real time health conditions of livestock. Animal health, breeding and vaccination records can also be locally stored and retrieved. 'Smart Tags' are capable of self-organizing into wireless ad-hoc networks for data reporting and retrieval.

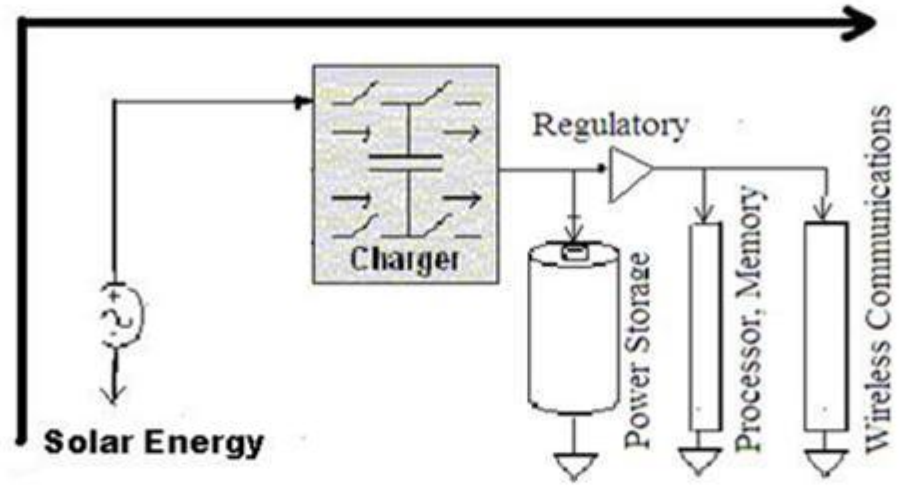

Figure 3. Electrical diagram of the energy-harvesting system

Features of a 'Smart Tag':

- Self-powered: Tags need no batteries
- Communicating: Tags wirelessly exchange data
- Sleep / wake: Tags optimize energy efficiency
- Security: All information is encrypted. All tags use unique identifiers.
- Location sensing: Tags are location-aware, can locate each animal.
- Health sensing: Tags may be equipped with health sensors (heartbeat, body temperature, pulse, etc.) for individual real-time monitoring. Can send alarm if health problems are detected.
- On-tag data storage: Tags also provide safe and secure data storage for vaccination records, milk production, etc.
- On-tag data processing: Tags have on-board processor to assist in tracking and monitoring health and location, information exchange, etc.

Testing of the ‘Smart Tag’ was done at the Agriculture Research and Development Center Dairy Facility of the University of Nebraska- Lincoln at Mead, Nebraska.

2.3 Methods

2.3.1 ‘Smart Tag’ test with battery as a power source

A ‘Smart Tag’ with a battery as a power source was used for this experiment to evaluate distance coverage of the ‘Smart Tag’. Materials used for this experiment were 1) a ‘Smart Tag’ Kit which contained a ‘Smart Tag’, a ‘Smart Tag’ receiver (Photo 2) and animal tag software, 2) a battery power source and 3) laptop computer.

Effective distance was measured from base station (laptop) to ‘Smart Tag’ both for a single hop and multi-hops (WSNs use two or more wireless hops to convey information from a source to a destination). Distance coverage and number of packets received were measured. A packet is the unit of data that is routed between an origin and a destination on the internet or any other packet-switched network. Distance coverage was measured as the distance covered from the base station (laptop) to the ‘Smart Tag’ (single hop) and also between multi-hops (n=6). To measure distance effectively FLUKE 421 D Laser Distance Meter equipment was used. Packets received were measured as packet counts received at the base station in every ten minutes from a particular distance. Thirty packets received by base station within ten minutes were assumed to be the best signal response.

For every test, temperature, humidity and wind speed measurements for a particular location were also taken from national weather station to evaluate their effect on packets received. A total of 240 observations were made. Data obtained were analyzed using the REG procedure of SAS (Version 9.2, SAS Institute Inc. 2009).

2.3.1.1 Effect of slope on signal response

This experiment was conducted at Prairieland Dairy located on Firth, Nebraska to evaluate signal responses on an area having a slope of 2% with barn barriers in the study field. Numbers of packets received within barn and between barns were collected with readings taken at every ten minutes. Two 'Smart Tags' were used in this experiment. Distance was fixed at 20 meters from base station for a single hop. Distances between multi-hops (tags) were also fixed at 20 meters.

2.3.2 'Smart Tag' test with solar as a power source

A 'Smart Tag' with a solar strip as a power source was used for this experiment to evaluate distance coverage. Materials used for this experiment were 1) a 'Smart Tag' Kit which contained 'Smart Tag' with solar strip, a 'Smart Tag' receiver and animal tag software, and 2) a laptop computer.

The methods for this experiment were similar to methods used for the 'Smart Tag' test with a battery as a power source. Two 'Smart Tags' were used for the multi-hop distance analysis. Other changes in methods were that the device was programmed to receive one packet every three minutes. Packets received were measured as packet counts received by base station in every nine minutes from a particular distance. Three packets received by the base station within every nine minutes were assumed to be best signal response. Time interval to receive packets was increased for the solar strip equipped ‘Smart Tag’ to minimize energy usage.

To optimize the sleep and wake function of ‘Smart Tag’ and to minimize the energy consumption for multi-hops; one ‘Smart Tag’ was designated the reference tag, the other tags were programmed to synchronize with the reference tag so that packets were received in base station in every three minutes. For every test, temperature, humidity and wind speed measurements for a particular location were also taken from the national weather station to evaluate their effects on signal response. A total of 70 observations were made. Data obtained were analyzed using the REG procedure of SAS (Version 9.2, SAS Institute Inc. 2009).

2.4 Sun exposure

To determine how much sun exposure is required to power up and to reach operational mode, the ‘Smart Tag’ was exposed for an hour in sunlight. Sun exposure is described as the state of sky and is measured on a percentage scale. When there are no clouds on the sky, sun exposure at that moment may be more than 95%. Electrical energy which was harvested by using the solar strip was stored in the capacitor of the ‘Smart Tag’. This stored electrical energy was measured in voltage by using RadioShack volt meter. Information about sun exposure was obtained from the national weather station.

2.4 Results

2.4.1 'Smart Tag' powered with battery source

2.4.1.1 Distance coverage for a single hop

Distance coverage was measured for a single hop 'Smart Tag'. In this experiment, initial distance was 10 meters from the base point (laptop). The farthest distance covered was 40 meters. After 40 meters no packets were received.

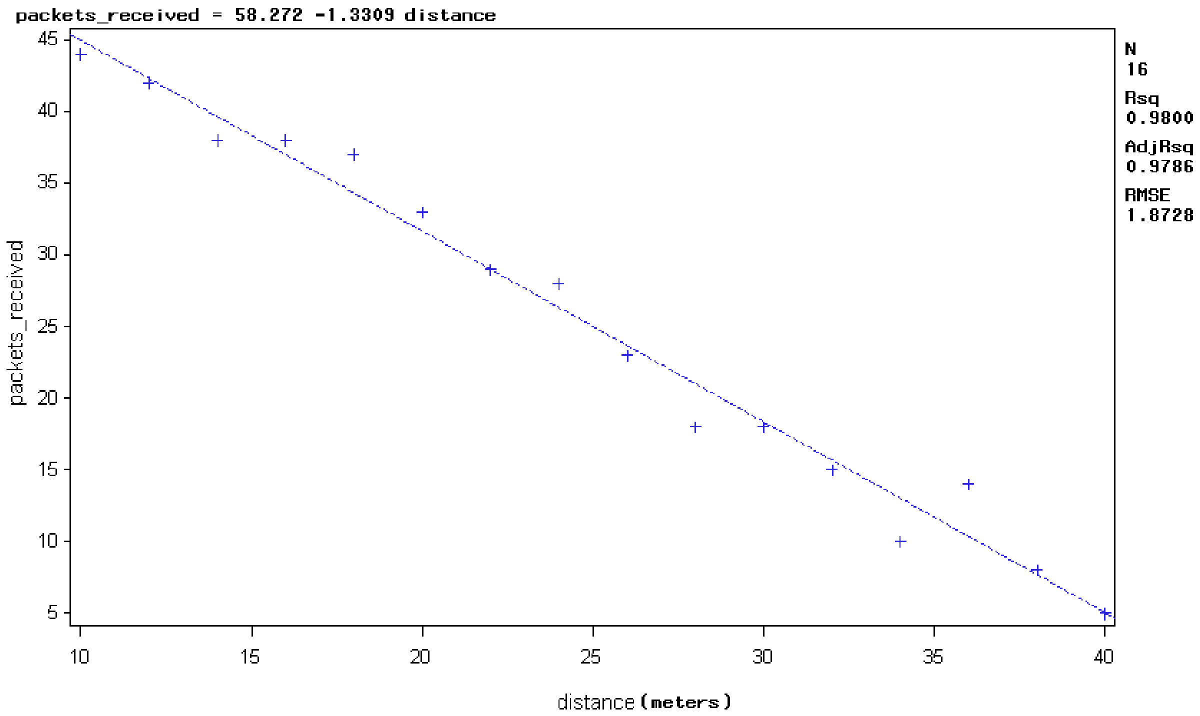

Figure 4. Regression line for regression of number of packets received on distance from base point.

Distance data were analyzed using Proc Reg (SAS). The mean distance for a single hop was 22.6 ± 1.38 m from where 30 packets were received by the base station. Number of packets received was taken as the dependent variable and distance was the explanatory variable.

There was a significant linear effect of distance ($p < 0.05$) on number of packets received. The estimate of the intercept $\hat{\beta}_0$ was 58.272 and the linear regression independent variable coefficient was -1.3309. So, the fitted line is: Packets received = 58.272 – 1.3309*distance (Fig. 4).

2.4.1.2 Effects of temperature, humidity and wind effect on packets received

Effects of temperature, humidity, and wind were estimated separately. Temperature (Fig. 5), humidity (Fig. 6) and wind (Fig. 7) had no effect on number of packets received ($p > 0.05$).

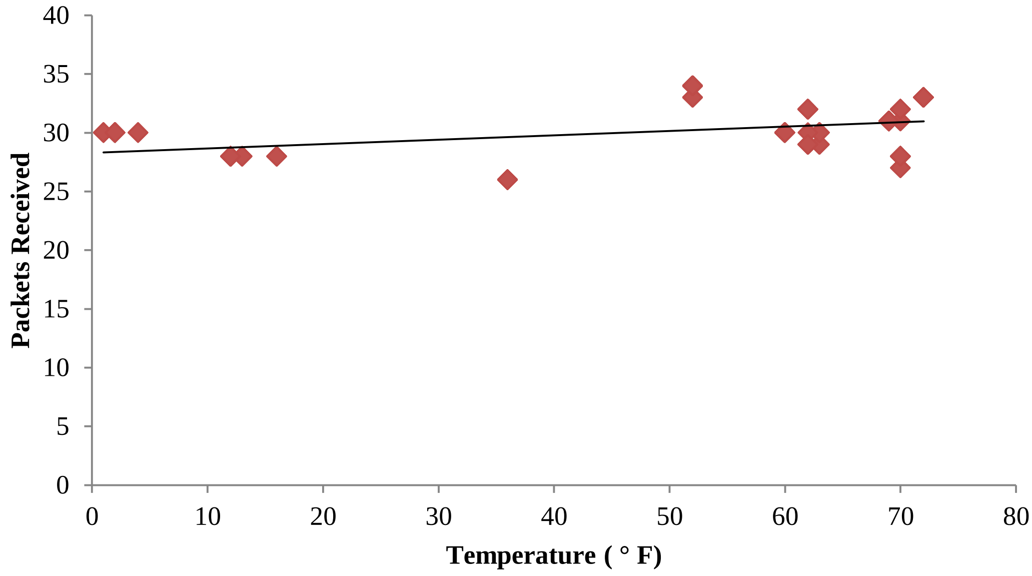

Figure 5. Effect of temperature on number of packets received.

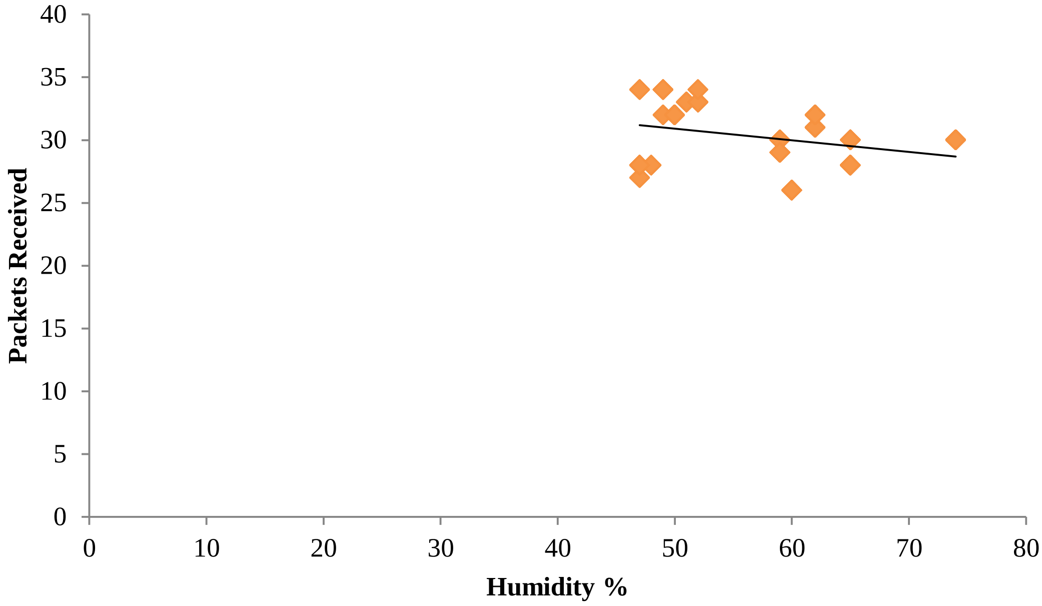

Figure 6. Effect of humidity on number of packets received.

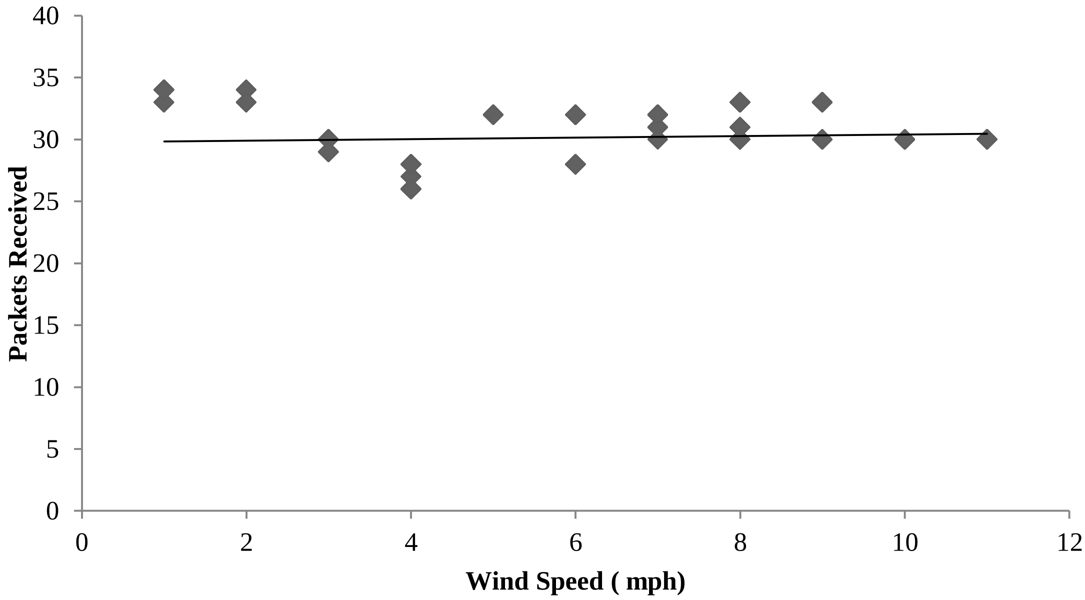

Figure 7. Effect of wind on number of packets received.

2.4.1.3 Distance coverage for multi-hops

Six 'Smart Tags' were used for this study. Distance coverage from the farthest 'Smart Tag' to the base station via multi-hops was 135.97 meters in the open field. Packets were wirelessly transmitted (Fig. 8) from one tag to another and to base station. The particular feature of these smart tags is they can form a wireless network, i.e., if more tags are connected, the larger the network will become and the larger the coverage area will be. The routing algorithm that has been designed helps a particular tag identify the nearest tag to send information back and forth to the base station.

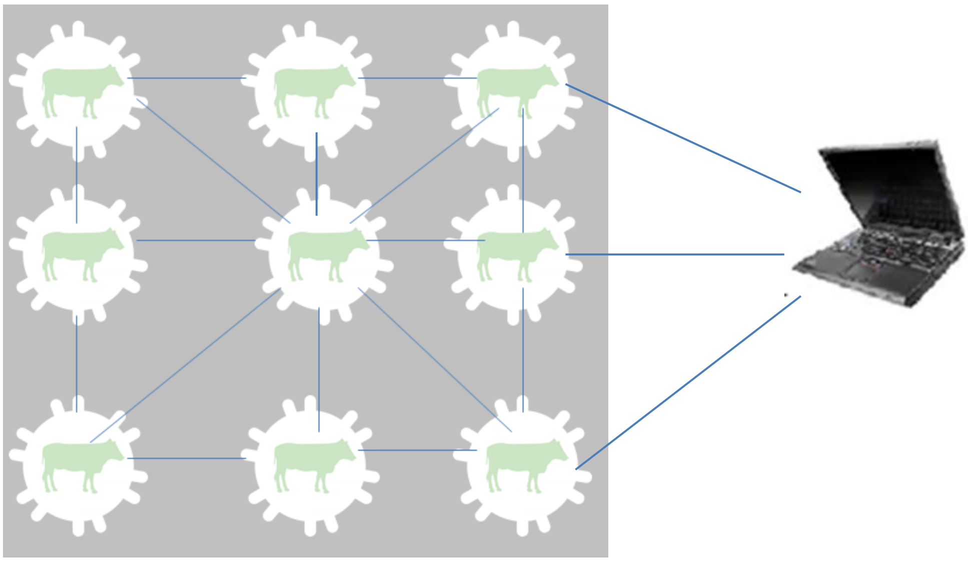

Figure 8. An example of packet transmission via multi-hops to base station

2.4.1.4 Effect of slope on signal response

For a barn slope of 2%, number of packets received at the base station was ranged from 27 packet counts to 35 packet counts in every ten minutes period. Between barns signal responses ranged from 26 to 30 packet counts (Fig. 9) and within barn signal responses ranged from 32 to 35 packet counts (Fig. 10). Even though the between barn packets received count was less than within barn, signal transmission seems promising even with a barn barrier (wall).

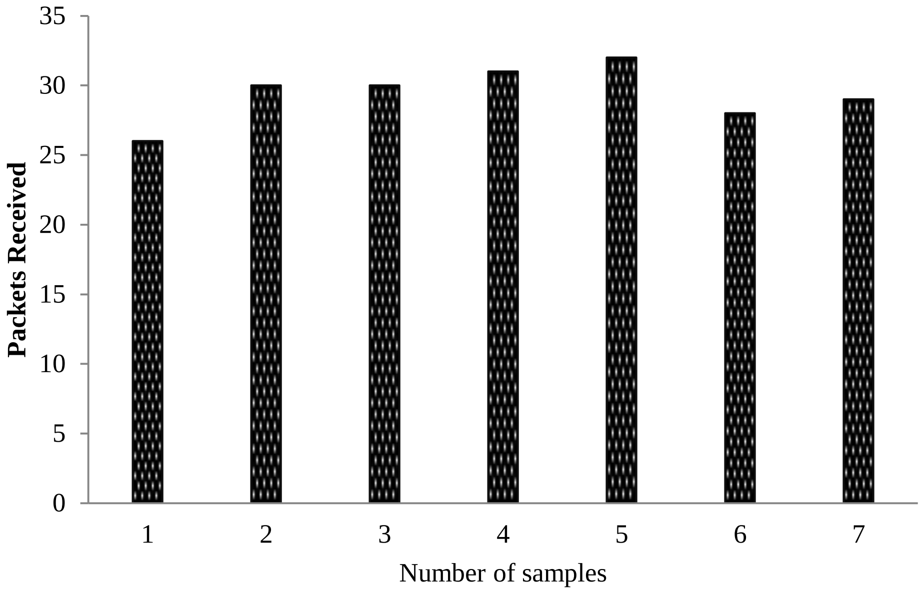

Figure 9. Bar diagram showing number of packets received between barns with of slope 2%.

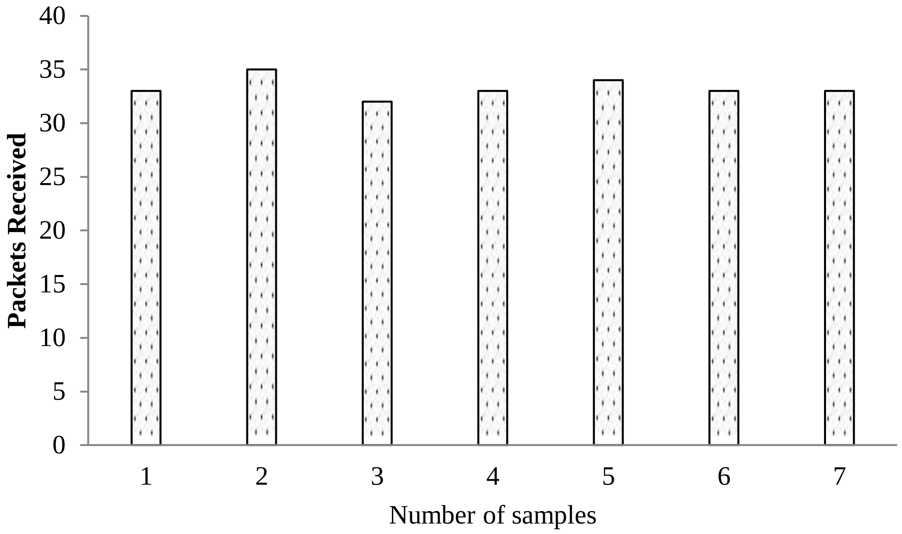

Figure 10. Bar diagram showing number of packets received within barn with of slope 2%.

2.4.2 'Smart Tag' with solar power source

2.4.2.1 Distance coverage for single hop

Distance coverage was measured for a single hop 'Smart Tag'. In this experiment, initial distance was 10 meters from the base station. The farthest distance covered was 29 meters (Fig. 11). After 29 meters no packets were received.

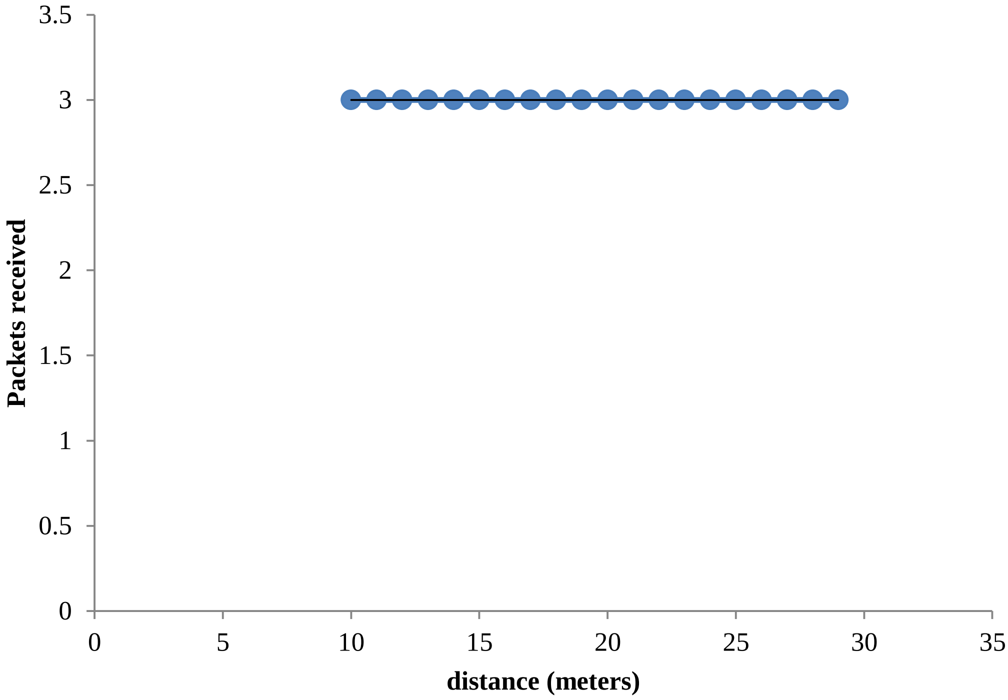

Figure 11. Regression line for regression of number of packets received on distance from base station.

The farthest distance for a single hop was 29 meters from where three packets were received by the base station in every nine minutes.

2.4.2.2 Effects of temperature, humidity and wind on number of packets received

Effects of temperature, humidity, and wind were estimated separately. Temperature (Fig. 12), humidity (Fig. 13) and wind (Fig.14) had no effect on number of packets received.

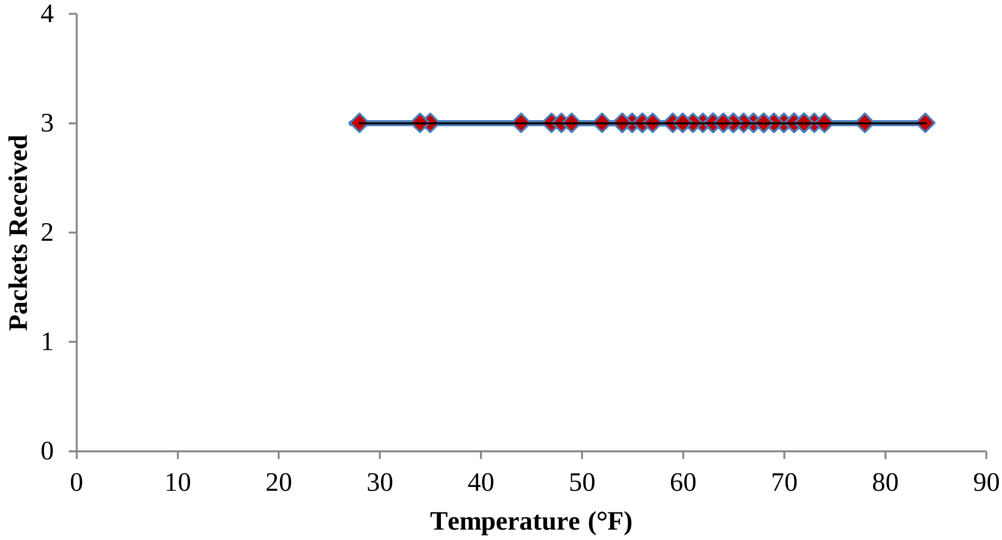

Figure 12. Effect of temperature on number of packets received.

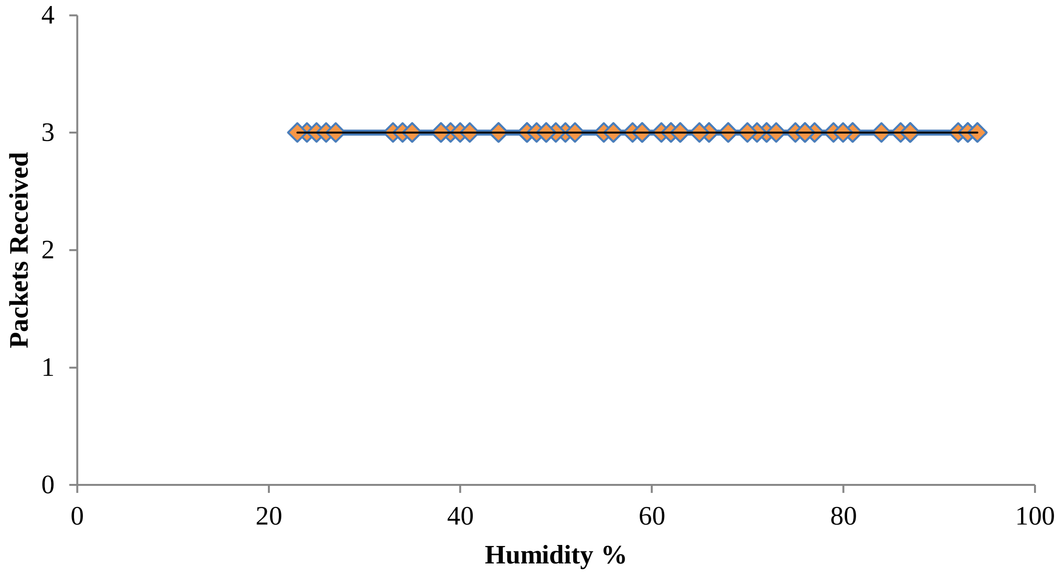

Figure 13. Effect of humidity on number of packets received.

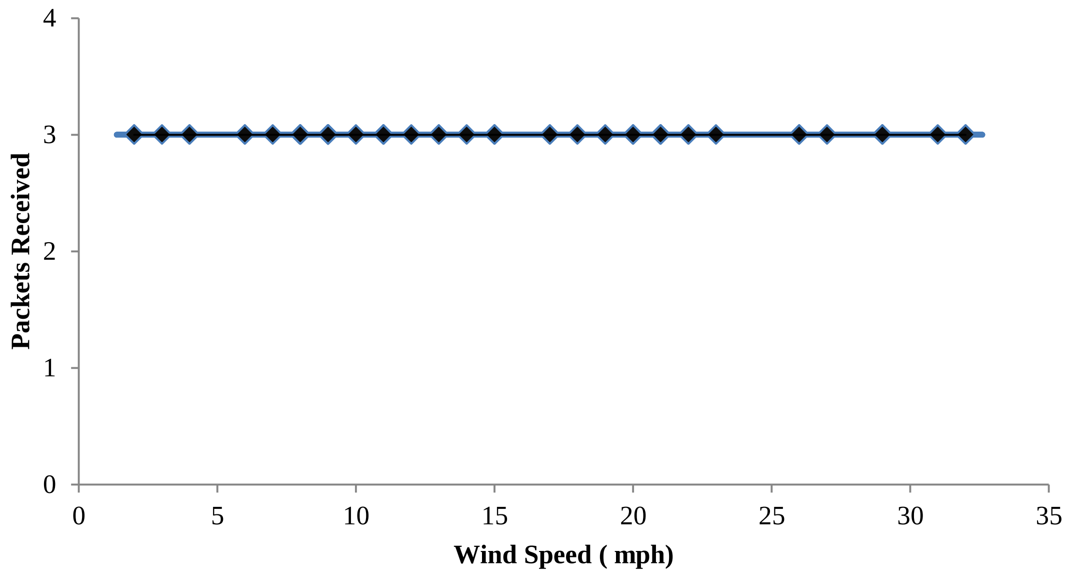

Figure 14. Effect of wind speed on number of packets received.

2.4.2.3 Distance coverage for multi-hops

Two ‘Smart Tags’ were used in this experiment. Distance coverage from the farthest ‘Smart Tag’ to the base station via multi-hops was 54 meters in the open field.

2.4.3 Sun exposure

Energy harvested from the solar strip is stored in the capacitor of the ‘Smart Tag’. The ‘Smart Tag’ begins to operate when the energy stored is more than 1.9 volt. Sun exposure of more than 35% seems sufficient for the solar strip to harvest enough solar energy to operate the ‘Smart Tag’. Figure 15 shows amount of sun exposure required to obtain electrical energy from solar strip. When sun exposure was about 90 %, electrical energy obtained was 3.1 volt per hour.

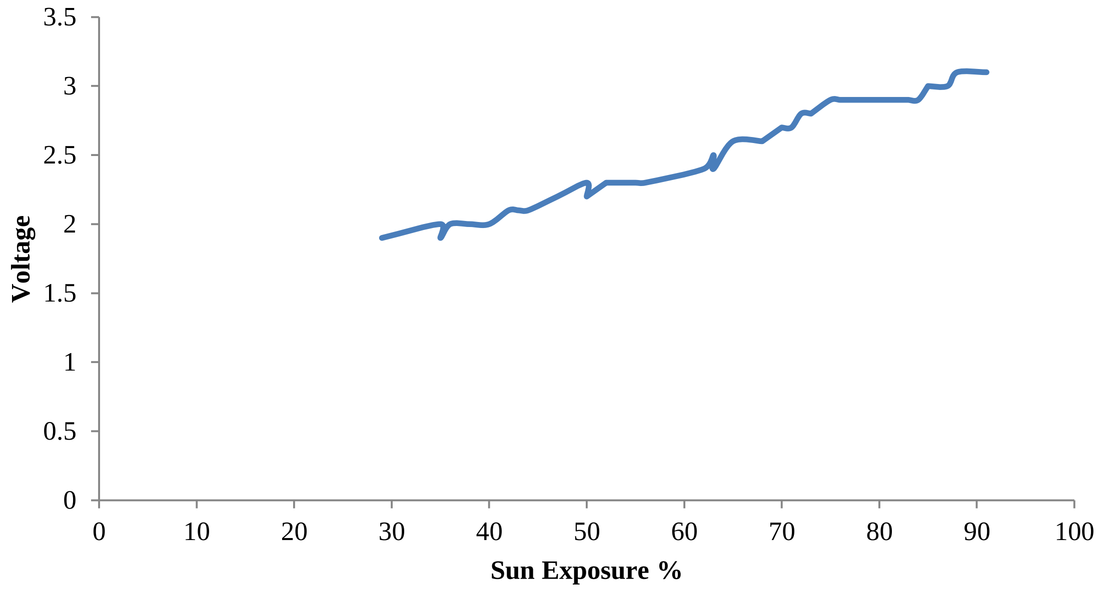

Figure 15. Voltage after keeping ‘Smart Tag’ for an hour in sunlight of various intensities.

2.5 Discussion

The test of a ‘Smart Tag’ with battery as a power source showed the working efficiency of prototype ‘Smart Tag’. Distance coverage was successful for multi-hops (n =6). Using solar powered ‘Smart Tags’, the single hop distance coverage was 29 meters and for multi-hops (n=2) distance coverage was approximately 54 meters. Due to ad–hoc wireless nature of ‘Smart Tags’ the true size of the network is limited by the number of available ‘Smart Tags’. The more tags that are connected, the larger the network will become and the larger the coverage area will be.

Temperature, humidity and wind speed had no effect on distance coverage in this study of battery powered and solar powered ‘Smart Tags’. Adverse weather conditions, however, may cause crystal frequency to shift, thermal noise level of transceiver to increase, and amplifiers to saturate, resulting in performance degradation of the radio device (Boano et al., 2010). Adverse weather conditions such as rainfall, snowfall and high wind speed may cause fading of signals (Nadeem et al., 2010).

Solar energy is one of the best alternatives to make ‘Smart Tag’ self-powered. This study showed that sun exposure of more than 35% is required to operate a ‘Smart Tag’.

2.6 Conclusions

'Smart Tag' is a self-powered, small, energy efficient wireless sensor tag that can cover a large area. Even though, solar energy seems promising to operate a 'Smart Tag', shortage of energy may arise during winter months when there is minimal sun exposure. This problem can be solved by developing better technology to harvest energy from different sources such as thermal and body vibration, and by developing more energy efficient sensor boards. Future work should focus on incorporating health sensors in 'Smart Tags'.

Literature cited

Akyildiz, I. F., W. Su, Y. Sankarasubramaniam and E. Cayirci. 2002. Wireless sensor networks: a survey, Computer Networks 38 (4): 393–422.

Baggio, A. 2005. Wireless sensor networks in precision agriculture. Proc. ACM workshop real-world wireless sensor networks. Accessed Dec.10, 2010. http://www.sics.se/realwsn05/papers/ baggio05wireless.pdf.

Boano, C.A., Brown, N. Tsiftes, U. Roedig, and T. Voigt. 2010. The impact of temperature on outdoor industrial sensornet applications. In IEEE Transactions on Industrial Informatics, 6 (3): 451–459.

Davis, D. P. 2002. Emerging animal diseases: global markets, global safety: a workshop summary. The national academies' board on agriculture and natural resources of the division on earth and life studies. USA.

Nadeem F., S. Chessa, E. Leitgeb, and S. Zaman. 2010. The effects of weather on the life time of wireless sensor networks using FSO/RF communication,Radio Engineering, 19 (2):262-270.

Radenkovic, M., and B. Wietrzyk. 2006. Wireless mobile ad-hoc sensor networks for very large scale cattle monitoring. Proc. 6th Int'l Workshop Applications and Services in Wireless Networks : 47–58. Accessed Jan. 12, 2011. http://www.wanrg.cs.nott.ac.uk/ papers/ASWN-MR_BW.pdf.

Wark, T., P. Corke, P. Sikka, L. Klingbeil, Y. Guo, C. Crossman, P. Valencia, D. Swain, and G. Bishop-Hurley. 2007. Transforming agriculture through pervasive wireless sensor networks. IEEE Pervasive Computing, 6(2):50–57.

Zhang, P., C. M. Sadler, S. A. Lyon, and M. Martonosi. 2004. Hardware design experiences in ZebraNet. In Proc. ACM SenSys, :227–238.

Chapter3. Cost-benefit analysis of ‘Smart Tag’ implementation.

3.1 Introduction

Torrey and Yolken (2005) stated that the most important reason for decline of ancient civilizations was the spread of infectious diseases. Many of these diseases were caused by microbes that had spread to humans from domesticated animals. An effective animal identification and tracking system is a current need of every country to protect animal and human health. Elbakadize (2008) concluded, “One of the options to prepare for a potential outbreak of an infections livestock disease is to initiate an animal tracking system, which would provide information on animal movements and facilitate disease management.”

Electronic animal identification and tracking, in case of an animal disease outbreak, could provide a quick and effective way to find all subsequently infected animals and herds. Action can then be taken to eradicate or prevent the spread of the disease. Various types of electronic animal identification systems are available such as passive and active RFID tags. These tags are, however, incapable of providing a complete tracking system. A ‘Smart Tag’ was designed and developed at the University of Nebraska for rapid and accurate identification of animals for tracking and health condition monitoring.

The ‘Smart Tag’ is built on wireless sensor network (WSN) technology which is new to animal producers. Before producers consider purchase of a ‘Smart Tag’ system, they need to understand the direct costs of ‘Smart Tag’ to compare with expected benefits. The objective of this study was to do a cost-benefit analysis of ‘Smart Tag’ implementation.

3.2 Materials and Methods

3.2.1 'Smart Tag' system costs

A Microsoft Excel spreadsheet tool entitled "RFID Costs" developed by Dhuyvetter and Blasi (2003) was slightly modified and used to estimate the cost of 'Smart Tag' implementation. The modified spreadsheet tool requires the user to provide critical pieces of information: interest rate, 'Smart Tag' cost, data accumulator (data accumulators are devices that accumulate information sent by the reader, e.g., laptop) cost, software and other costs (subscription, labor and internet outlays), useful life, salvage value and percentage of the component cost that should be applied to the 'Smart Tag' system. Interest rate, investment life, initial investment, and salvage value were used to estimate the annualized costs of the management system.

The initial cost of each 'Smart Tag' was fixed at ten dollars. Useful life of 'Smart Tag' was five years. Interest rate was set at 6.5%. Data accumulator cost, software and internet access costs, subscription/upgrade fees and labor costs were taken without adjustment from Dhuyvetter and Blasi (2003).

Mus (2006) explained the variables used to provide cost estimation of RFID tags. The modified model takes into account the following variables to provide cost estimation of 'Smart Tag' system,

Where,

D = annual depreciation rate (%),

I_V = initial value of equipment (US dollars),

S_V = salvage value of equipment (US dollars),

E_L = expected life of the equipment (years),

R = annual interest rate (%),

r = monthly interest rate (%),

t = time (month),

T = time (year),

A.I.C. = accrued interest cost ,

S_H = size of herd (number of dairy cows),

P = fraction of equipment cost assigned to 'Smart Tag' system, and

M = monthly cost of the operational activity

Initial equipment cost used in the model for cost computation was depreciated over number of years depending on the expected life of the equipment. Equation 2.1 was used to compute the annual depreciation cost of the equipment.

$$D = \frac{I_V - S_V}{E_L} \tag{2.1}$$

Depending upon the equipment (tags, data accumulator, and software) the model divides cost into investment and operational costs. To find the interest cost of equipment equation 2.2 was used.

$$A.I.C. = \sum_{i=1}^{N} (I_V - D * T_{i-1}) * R \tag{2.2}$$

Equation 2.3 was used to find total annual cost of equipment per animal taking into account interest cost as well as initial value of equipment. Equation 2.3 was used to compute cost of the equipment for various herd sizes.

$$\text{Cost of equipment per animal} = \frac{\left[\left(\dfrac{A.I.C. + I_V}{E_L}\right) * P\right]}{S_H} \tag{2.3}$$

As stated earlier, the cost of the 'Smart Tag' system is split into investment and operational costs, which include costs of Smart Tags, internet access, subscription fees and labor. Equation 2.4 is used to calculate operational cost per animal. The computation is similar to computation of an annuity.

$$\text{Operational cost per animal} = \frac{\left[\left(\dfrac{(1+r)^t - 1}{r}\right) * M\right] * P}{S_H} \tag{2.4}$$

The sum of results from equations 2.3 and 2.4 is the annual per animal cost of a 'Smart Tag' system.

3.2.2 'Smart Tag' cost projection

The 'Smart Tags' can be reused. A dairy herd was taken as an example. A spreadsheet model was developed with assumptions of a yearly 30% cull rate and a 50% reuse rate to compute yearly costs of 'Smart Tags' for five years assuming a fixed cost of each 'Smart Tag' of ten dollars.

3.2.3 'Smart Tag' benefits

The 'Smart tag' system can provide many benefits but not all can be quantified easily. To describe some benefits in monetary terms for dairy cattle industry, an interactive dairy farm income calculator entitled "Dairy farm income and cash flow calculations" was developed by Keown and Dhakal (2010) and was used in this study. It can be downloaded at http://www.ianrpubs.unl.edu/epublic/live/g2034/build/g2034.pdf . A 5% reduction in labor and in miscellaneous costs was assumed.

3.3 Results

3.3.1 Costs of 'Smart Tag' Systems per year

For large herds ranging from 2,000 to 8,000 animals the cost of a 'Smart Tag' system per animal was between $12.14 and $11.80 (Fig. 16).

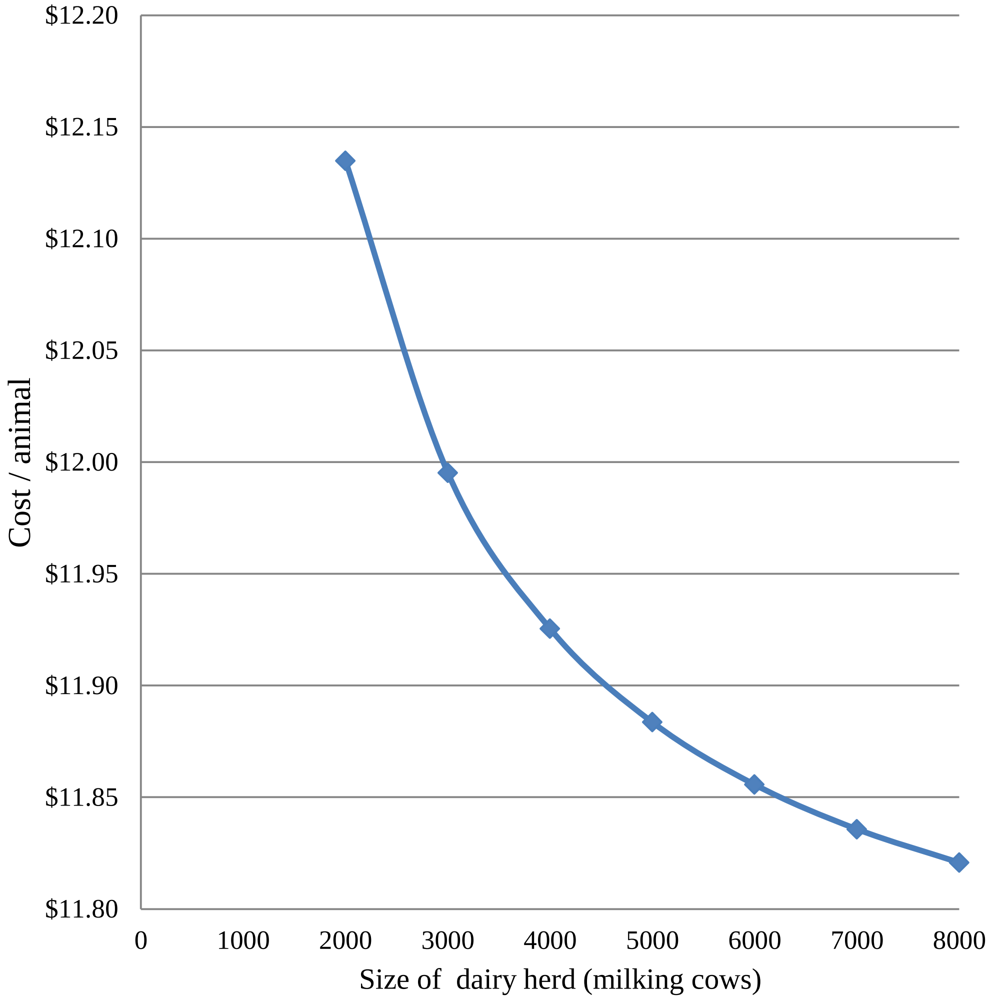

Figure 16. Total annual cost of a 'Smart Tag' system in dairy herds ranging from 2,000 to 8,000 animals.

For smaller herds ranging from 100 to 400 animals the cost of a ‘Smart Tag’ system per animal was between $20.00 and $13.81 (Fig. 17).

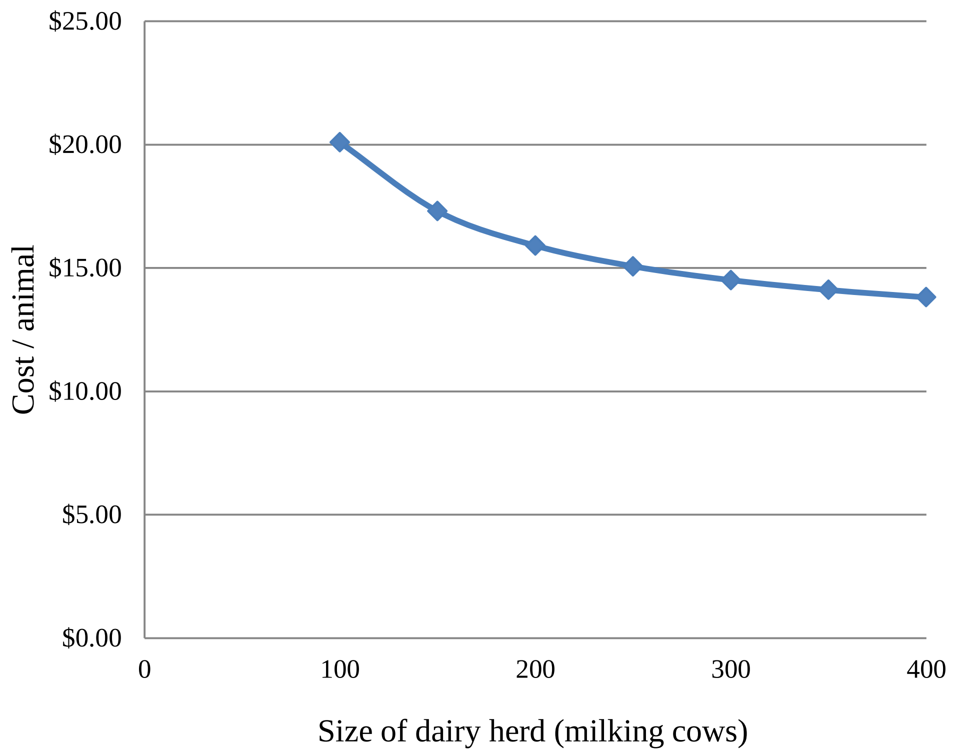

Figure 17. Total annual cost of a ‘Smart Tag’ system in dairy herds ranging from 100 to 400 animals.

The non-linear relationship between cost and herd size is due to spreading out fixed costs over a larger number of animals. The fixed and variable costs per animal decrease as herd size increases.

3.3.2 Projection of ‘Smart Tag’ system costs for five years

A herd size of 400 was assumed for cost projection of a ‘Smart Tag’ system for 5 consecutive years. In the first year the cost was $4000.00, in the second year the cost was $600.00, in the third year the cost was $1020.00, in the fourth year the cost was $1314.00, and in the fifth year the cost was $1519.80 (Fig. 18). The total cost for a ‘Smart Tag’ system for a dairy herd of size 400 for 5 years was projected to be $8453.80.

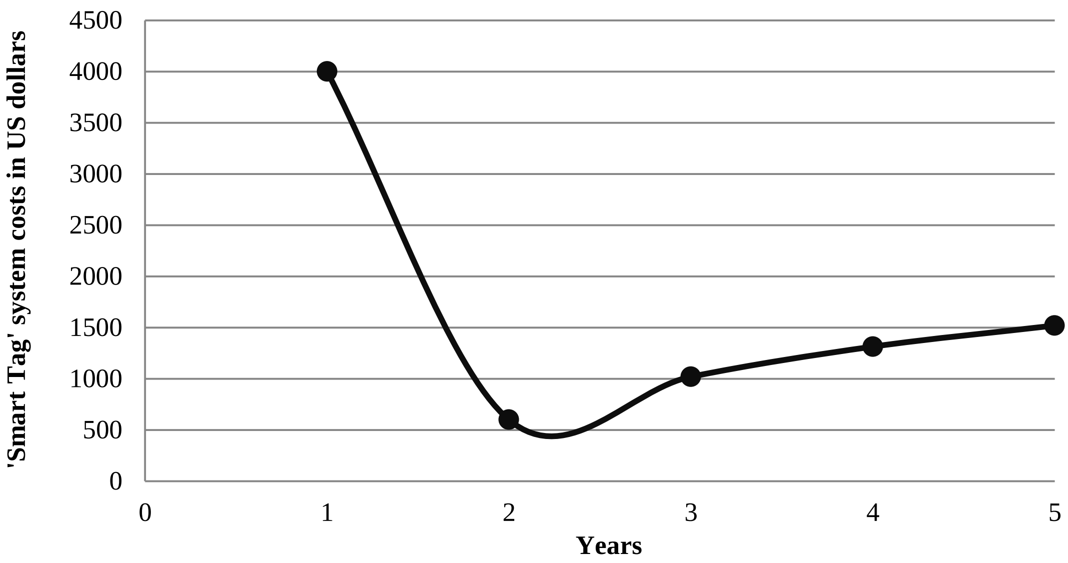

Figure 18. Cost of a ‘Smart Tag’ system for each five consecutive years in a dairy herd of size 400.

3.3.3 Value of ‘Smart Tag’ benefits

Net income would increase with use of a ‘Smart Tag’ system. The increase in net income is less in small size herds. As herd size increases the difference between net income and net income due to use of a ‘Smart Tag’ system increases (Table 5, Fig. 19 and Fig. 20).

Table 5. Net income with and without a ‘Smart Tag’ system for different herd sizes

Herd Size	Net Income in US Dollars[a]	Net income in US Dollars[b]	Difference (a-b) in US Dollars
100	36,892	34,708	2,184
150	55,338	52,063	3,275
200	73,783	69,417	4,366
250	92,229	86,771	5,458
300	110,675	104,125	6,550
350	129,121	121,479	7,642
400	147,567	138,833	8,734
2,000	737,833	694,167	43,666
3,000	1,106,750	1,041,250	65,500
4,000	1,475,667	1,388,333	87,334
5,000	1,844,583	1,735,417	109,166
6,000	2,213,500	2,082,500	131,000
7,000	2,582,417	2,429,583	152,834
8,000	2,951,333	2,776,667	174,666

a = Net income with ‘Smart Tag’ system,

b = Net income without ‘Smart Tag’ System

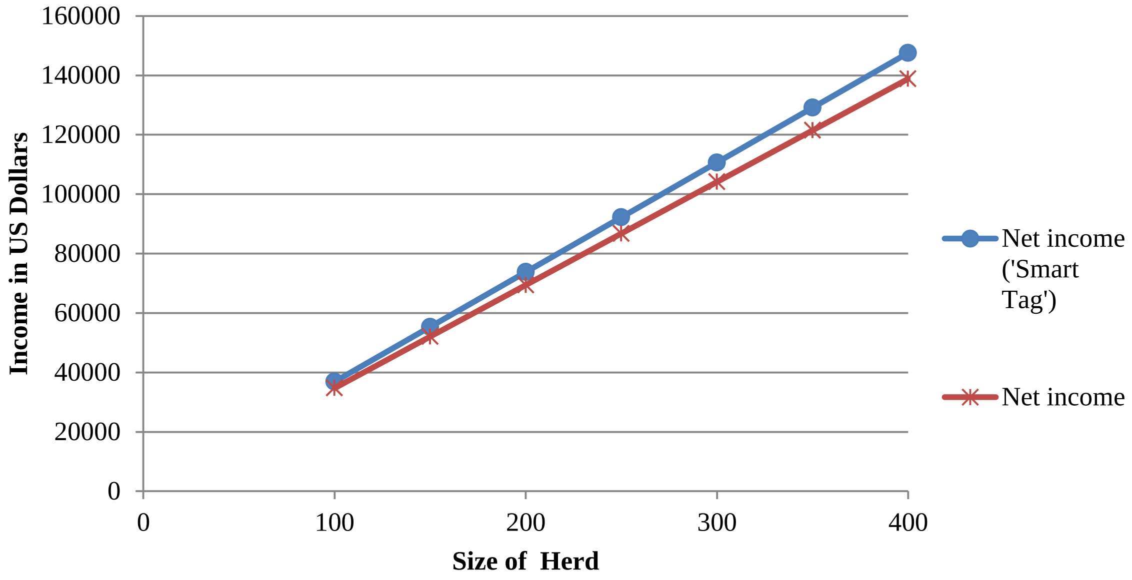

Figure 19. Net income with and without a ‘Smart Tag’ system in dairy herds ranging from 100 to 400 animals.

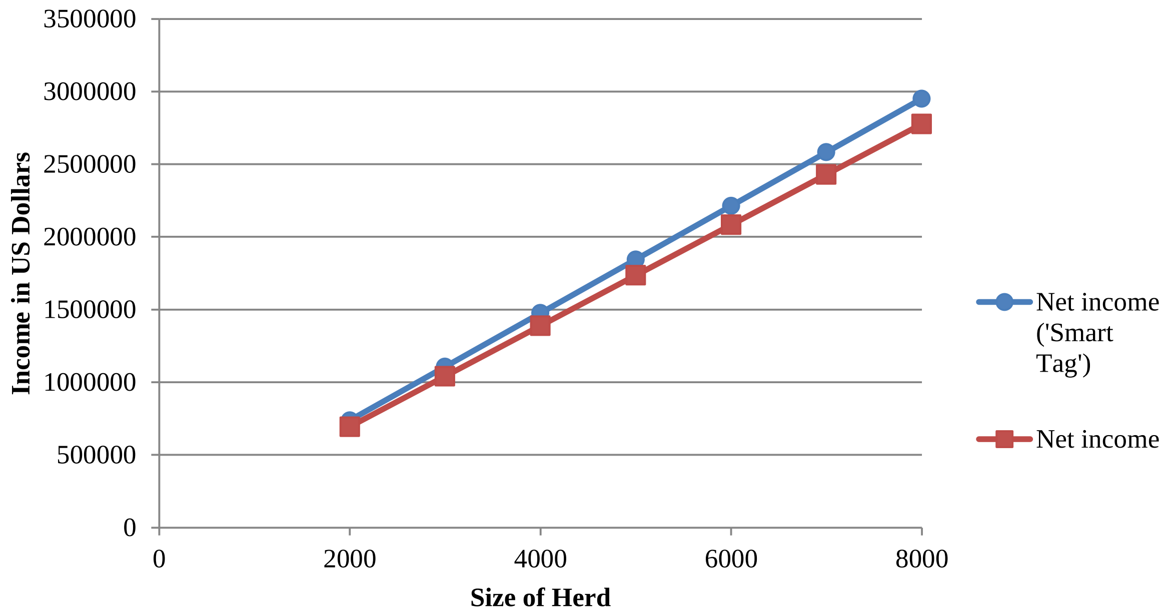

Figure 20. Net income with and without a ‘Smart Tag’ system in dairy herds ranging from 2,000 to 8,000 animals.

3.4 Discussion

The initial cost of 'Smart Tag' system is much greater than for current electronic RFID tags found in market. The cost of each 'Smart Tag' for smaller herds was greater than for larger herds because in larger herds fixed costs are spread over a larger number of animals. The fixed and variable costs per animal decrease as herd size increases.

Even though current market RFID tags are less expensive they do not reliably track animals and they require usage of batteries for operating. In contrast, 'Smart Tags' are wireless, eco-friendly and can be recoded and reused. In the long term a 'Smart Tag' system would be beneficial for animal producers because of unique features such as accurate and rapid animal identification, tracking and health monitoring.

The animal tracking property of 'Smart Tag' would help in 'farm to fork' traceability. Proper animal identification and tracking functions would reduce the impact of outbreaks of diseases because instantaneous tracking would be available to locate animals and herds to quarantine. According to Elbakadize (2008), "The sooner the information on animal movement is available to be accessed, the sooner appropriate response actions will be implemented to halt the disease spread. Decreasing the time necessary to trace animal movement substantially decreases the loss that could be suffered due to outbreak of highly contagious animal disease such as Foot and Mouth Disease (FMD)." In addition to, animal tracking and identification benefits, there are many other benefits of 'Smart Tag', such as data security, history record and health monitoring as shown in Figure 21.

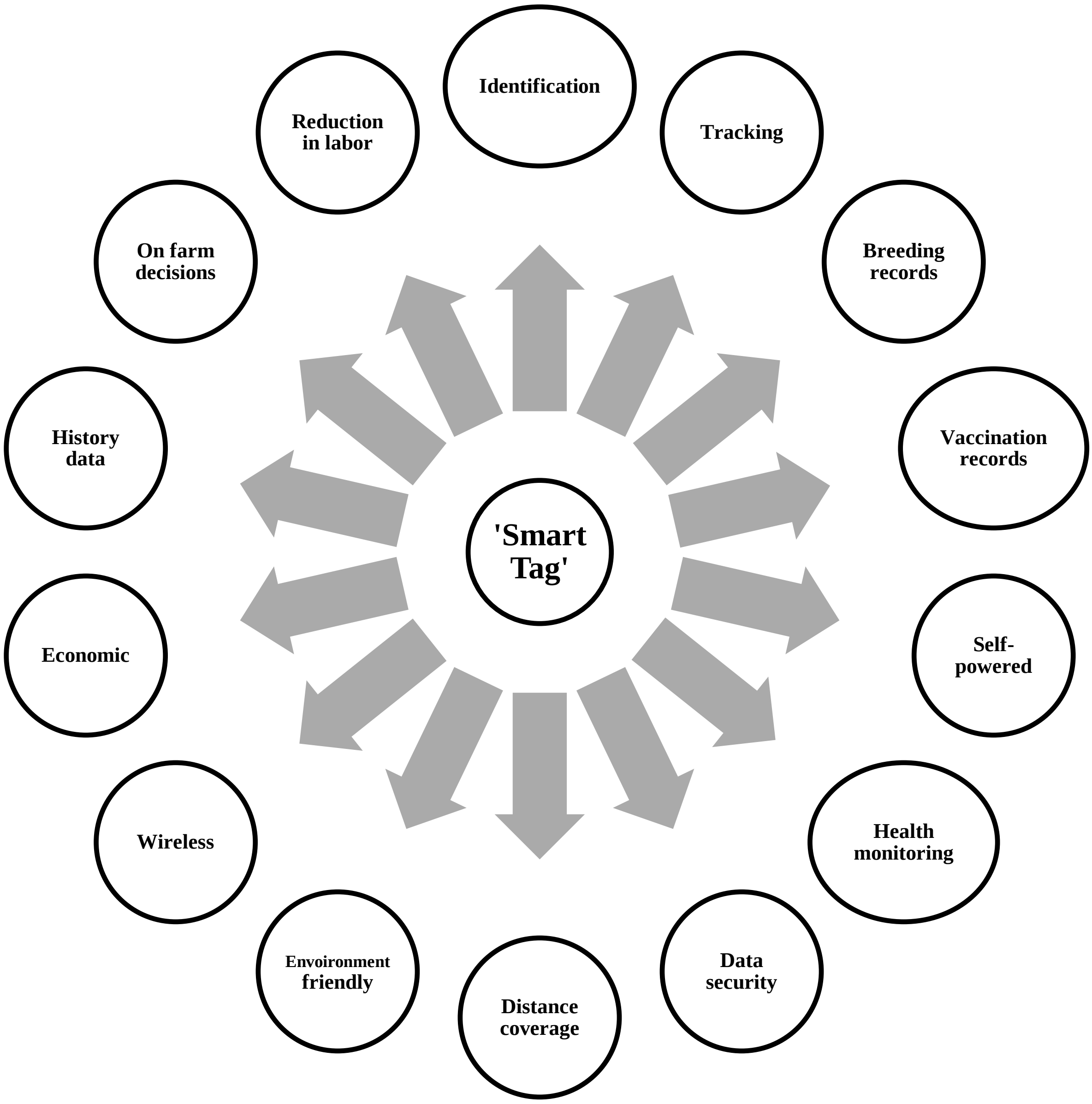

Figure 21. Potential benefits of the ‘Smart Tag’ system over RFID tag systems currently in use.

3.5 Conclusions

The initial costs of ‘Smart Tag’ system are greater than other animal identification tags currently available. However, due to its unique features such as being self-powered, having greater distance coverage, and having health monitoring sensors; the benefits will outweigh the investment cost in the long run.

‘Smart Tag’ systems would be more beneficial in livestock production environments than other animal identification technologies due to its peculiar features such as encrypted information for data privacy, wireless identification, and its ability to operate purely on energy harvested from its environment such as solar power. Considering the large number of animals that need to be tagged according to USDA traceability requirements, including 104.8 million cattle and 65.1 million hogs, a complete solution such as ‘Smart Tag’, has the potential for economical and social impacts as seen in other emerging technologies. Costs would be expected to decrease as the technology is adopted.

Literature cited

Dhuyvetter, K. and D. Blasi. 2003. RFID costs.xls. Accessed May 7, 2011. http://www.agmanger.com.

Elbakidze, L. 2007. Economic benefits of animal tracing in the cattle production sector. Journal of Agricultural and Resource Economics, 32, 1:169-180.

Keown, J. F., and K. Dhakal. 2010. NebGuide 2034. Dairy farm income and cash flow calculations. Accessed May 10, 2011. http://www.ianrpubs.unl.edu/epublic/live/g2034/build/g2034.pdf.

Mus, M. 2006. Traceability system approaches and cost analysis for the beef industry. MS Thesis, Washington State University.USA.

Torrey, E.F. and R.H. Yolken. 2005. Beasts of the earth: animals, humans, and disease. New Brunswick, New Jersey, NJ: Rutgers University Press. P: 140

Appendices

Appendix 1. 'Smart Tag' system cost model

Estimated Costs for a 'Smart TagSystem

Average herd size, number of head	400
Interest rate, %	6.5%

Smart Tag' Components

	Description	Initial cost, $ Total	Initial cost, $ Per Head	Useful life, yrs	Salvage value, $	Annual Cost, $	Percent to Smart	Smart Tag Cost Total	Smart Tag Cost Per Head
Smart Tag'									
	Smart tag	---	$10.00	---	---	$4,130	100%	$4,130	$10.33
		---		---	---				
	Tags for cows (one-time purchase)	---	$10.00	5	0	$963	100%	$963	$2.41
Data accumulator									
	Laptop computer	$1,000		4	200	$247	25%	$62	$0.15
Software / web-based analysis and storage									
	Computer software	$700		5	0	$168	50%	$84	$0.21
Other									
	Internet access	$480		---	---	$496	25%	$124	$0.31
	Subscriptions/upgrade fees	$100		---	---	$103	50%	$52	$0.13
	Labor	$500		---	---	$516	100%	$516	$1.29
				---	---				
Total annual cost								**$5,930**	**$14.83**

Appendix 2. Dairy farm income and cash flow calculations model

	Update	Default		Values Used in model
Price Per CWT		12.5		12.5
CWT Per Cow		263		263
Herd Size		6000		6000

INCOME:	AMOUNT	PER CWT	PER COW	PERCENT	Update	Default Values Per cow
Milk	$19,725,000	$12.50	$3,288	100.00		
Total income	**$19,725,000**	**12.50**	**$3,288**	**100.00**		
EXPENSES						
Feed:						
Hay	780,000	0.49	130	3.95		$130
Silage	2,352,000	1.49	392	11.92		$392
DDG - Gluten	588,000	0.37	98	2.98		$98
SBM - Soybest	852,000	0.54	142	4.32		$142
Grain	858,000	0.54	143	4.35		$143
Other Feed - Supplements	1,452,000	0.92	242	7.36		$242
Total feed	**$6,882,000**	**$4.35**	**$1,147**	**34.89**		
Herd replacement cost:						
Depreciation - dairy cows	1,398,000	0.89	233	7.09		$233
Other Costs	648,000	0.41	108	3.29		$108
Total herd replacement cost	**$2,046,000**	**$1.30**	**$341**	**10.37**		
Other operating expenses:						
Interest and rent	1,248,000	0.79	208	6.33		$208
Labor plus benefits	1,925,000	1.22	321	9.76		$321
Depreciation - other	918,000	0.58	153	4.65		$153
Milk hauling	402,000	0.25	67	2.04		$67
Industry assessments	252,000	0.16	42	1.28		$42
Supplies	1,002,000	0.63	167	5.08		$167
Repair and maintenance	870,000	0.55	145	4.41		$145
Utilities	348,000	0.22	58	1.76		$58
Taxes and licences	264,000	0.17	44	1.34		$44
Insurance	258,000	0.16	43	1.31		$43
Fuel and oil	303,500	0.19	51	1.54		$51
Legal and accounting	144,000	0.09	24	0.73		$24
Veterinary and breeding	516,000	0.33	86	2.62		$86
Testing and trimming	156,000	0.10	26	0.79		$26
Hauling livestock	36,000	0.02	6	0.18		$6
Miscellaneous	72,000	0.05	12	0.37		$12
Total other expenses	**$8,714,500**	**$5.51**	**$1,452**	**44.18**		
Total expenses	**$17,642,500**	**$11.16**	**$2,940**	**89.44**		
NET INCOME	**$2,082,500**	**$1.34**	**$347**	**10.56**		